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Construction Engineering Research Laboratory

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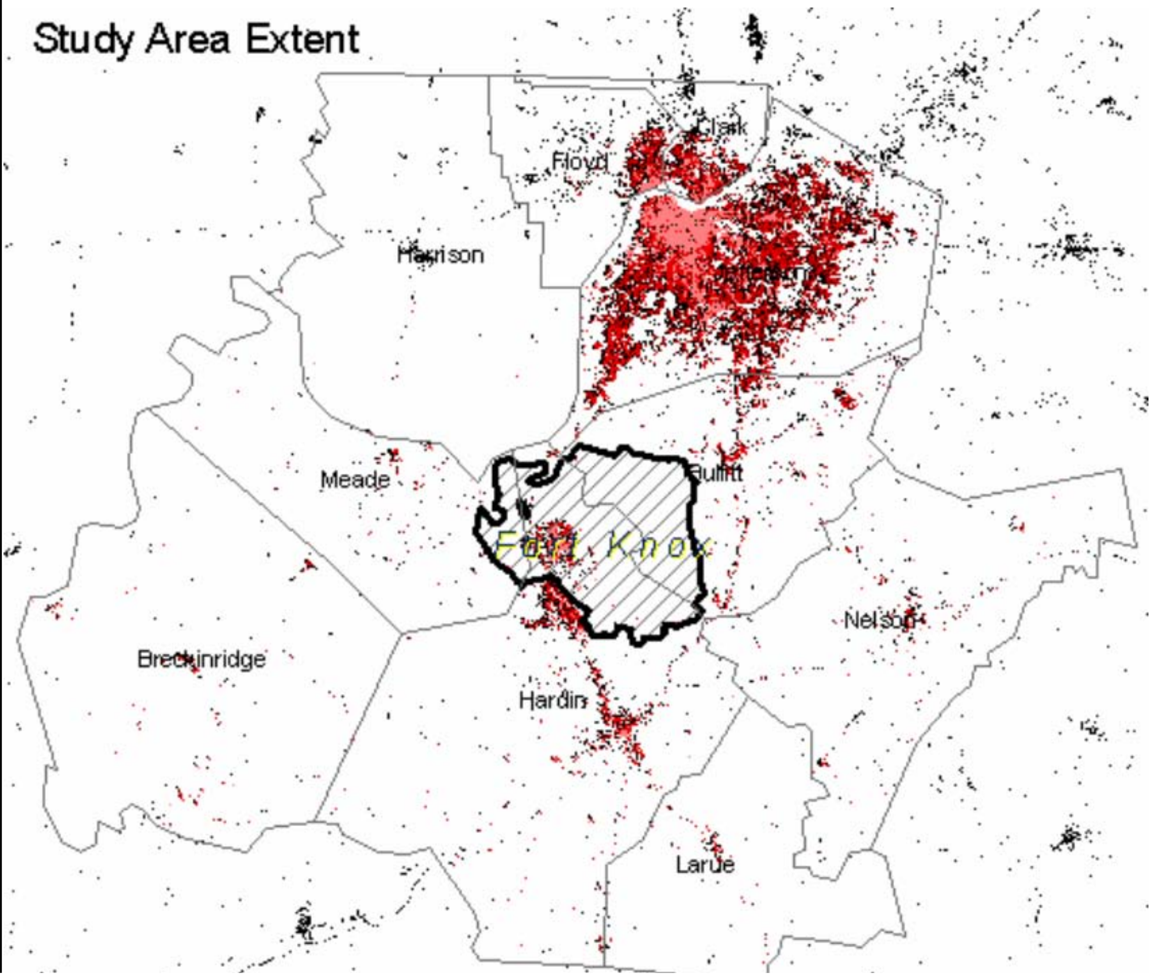
Engineer Research and Development Center

Fort Knox Trend Analysis, Encroachment Study, and Perimeter Expansion Opportunities in Support of Military Training

Bruce MacAllister, Robert Lozar, James Westervelt, Michael White, and Joseph Rank

March 2006



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Final Report

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Prepared for

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ABSTRACT: This project used geographic information system (GIS) map layers in an analysis of historic land use and growth in the region. These GIS layers were then used again as input to the LEAM Land Use Change model to project urban growth around Fort Knox into the future. Historical land use maps, current and future highway system plans, and municipal zoning information all contributed to forecasting residential and commercial development.

The historic trend has been a growth rate of roughly 2% per decade in the region surrounding Fort Knox. In 1972, the percent of urban development here was 1.37%. That figure grew to 6.54% in 2001 and will continue to rise as more and more of the area becomes attractive to people to build there. The prospect for the future, however, is that civilian encroachment around Fort Knox will only continue.

Model simulations indicate that the areas south and west of Fort Knox are those at the greatest risk for urban encroachment, although there is substantial urban sprawl emanating from Louisville to the north. One way to limit future urban encroachment would be to use those areas identified in the Southeastern Ecological Framework Study as a starting point in investigating potential opportunities for conservation agreements between Fort Knox and surrounding land holders. A scenario using the Framework was modeled for this project.

Executive Summary

Urban encroachment threatens the mission of Fort Knox to provide realistic military training to the soldiers of the United States Army. This study provides Fort Knox with options that can proactively mitigate conflicts between the Army and the growing civilian community that surround this installation.

This project used geographic information system (GIS) map layers in an analysis of historic land use and growth in the region. These GIS layers were then used again as input to the LEAM Land Use Change (LEAMluc) model to project urban growth around Fort Knox into the future. Historical land use maps, current and future highway system plans, and municipal zoning information all contributed to forecasting residential and commercial development.

The historic trend has been a growth rate of roughly 2% per decade in the region surrounding Fort Knox. In 1972, the percent of urban development here was 1.37%. That figure grew to 6.54% in 2001 and will continue to rise as more and more of the area becomes attractive to people to build there. A closer analysis revealed that areas within a 1-mile buffer of the installation shows a similar growth pattern (6.4% of this buffer was urban in 2001). When a 5-mile buffer is drawn around the installation, the picture improves slightly, with only 4.4% of this area showing urban land use. The prospect for the future, however, is that civilian encroachment around Fort Knox will only continue.

Model simulations indicate that the areas south and west of Fort Knox are those at the greatest risk for urban encroachment, although there is substantial urban sprawl emanating from Louisville to the north. The army can best avoid potential conflicts involving incompatible land use practices by examining their long-term range plan. Repositioning certain training assets away from the southern portion of the installation will decrease the potential for noise complaints from future residential neighborhoods. However, a better alternative would be to use those areas identified in the Southeastern Ecological Framework Study as a starting point in investigating potential opportunities for conservation agreements between the Fort Knox and surrounding land holders.

A number of private land owners and Non-Government Organizations such as The Nature Conservancy and The Conservation Fund have an interest in preserving

areas of native forest and wetlands in northern Hardin County, KY. Land purchases (where feasible) or conservation agreements between Fort Knox and these land holders would provide buffer zones along the installation perimeter where development would be excluded. No military training activities could be performed within these buffers, but development from the nearby cities of Radcliff, Elizabethtown, and the surrounding communities would also be restricted.

Contents

List of Figures and Tables

Figures

Tables

Preface

This study was conducted for Fort Knox, KY, under MIPR4MDDK00033, “Knox Encroachment”; 7H06H6, “Fort Knox Trend Analysis, Encroachment Study, and Perimeter Expansion Opportunities in Support of Military Training.” The technical monitor was Bill Goran, CVT.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Bruce A. MacAllister. Part of this work was done by The Pertan Group, Champaign, IL, under contract DACA42-01-D-0002, Delivery Order 12. Alan B. Anderson is Chief, CN-N, and Dr. John T. Bandy is Chief, CN. The associated Technical Director was William Severinghaus, CVT. The Acting Director of CERL is Dr. Ilker Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Fort Knox, KY, is facing constraints on mission activities due to land use changes near its periphery. The presence of these concerns is putting pressure on the installation trainers to modify military mission activities within the installation boundaries. Such concerns are often described as "encroachment." Since Fort Knox is increasingly asked to alter activities within its boarders, it has become clear that there is a need to better define the historic trend of development, project that trend to the immediate future, and identify key opportunities for land preservation and cooperative conservation agreements with land holders within a 1-mile buffer around the installation and across the region. These efforts will most effectively minimize future impacts on its training and readiness mission.

Background

Military installations are facing constraints on mission activities due to land use changes near their boundaries. With changes, such as urbanization, problems arise between civilian and military interests, including community concerns about limiting noise, dust, and traffic, and trainers concerns about radio interference, light interference in night training, and other issues. The presence of these concerns is causing the installation trainers to decrease military mission activities near the installation boundaries. Such concerns are often described as "encroachment." The Defense Senior Readiness Oversight Committee defines encroachment as "any outside activity, law or pressure that affects the ability of military forces to perform the mission assigned to the installations." Military installations are increasingly asked to alter activities within their boundaries to alleviate these conflicts. Examples include restricted flight routes, eliminated firing ranges, and threats to firing operations. Such restrictions to operations can limit installations' abilities to meet vital mission requirements.

To deal with these issues effectively, an installation planner needs to establish two "trajectories of change":

1. Establish clearly the historic urban growth in areas surrounding a military installation
2. Provide intelligently based projections of future growth and change.

Military and civilian planners can cooperate in anticipating future land use patterns and devising appropriate mitigation strategies to avoid or otherwise deal with potential conflicts before they occur. In planning, problem avoidance is usually much less expensive and more effective than mitigation after the fact.

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL), Champaign, IL, has engaged in several research projects to develop and apply tools for such risk assessment.

To address the question of historical urban growth, ERDC/CERL has developed an approach with illustrations that depict the changes in land use around an installation. This visual presentation quickly conveys the potential for conflicts as the separation between military lands and the neighboring community disappears. Each series consists of several snapshots of the physical environment of an installation and its surrounding region. Presented one after another, this is a powerful tool for showing the changing conditions around an installation.

Objectives

This study was conducted with a number of specific objectives:

1. To define the historic trend of development surrounding Fort Knox
2. To project that trend to the immediate future.
3. To identify key opportunities for land acquisition/preservation within a 5-mile buffer around the installation.

These objectives were designed with one goal in mind: to help effectively minimize future impacts of civilian urban development on the training and readiness mission of Fort Knox.

Approach

Predictions of urban land use patterns can be made analyzing historical data. This report contains the steps involved in obtaining and examining the historic land use information which was used to determine historic trends in development around Fort Knox. Taking the analysis one step further, the data available in various archives were used to predict those trends into the future.

Mode of Technology Transfer

The study described in this report has been developed for Fort Knox, the Army, and the Department of Defense (DoD). The results of this study are made available to the appropriate personnel via this technical report and may be leveraged with other appropriate simulation technologies, as well as assessment and planning environments, to aid Directorate of Base Operation Support (DBOS), trainers, and installation commanders in the decision-making process.

Future projections in the form of maps of urban development surrounding Fort Knox have been created by the LEAMluc model and are accessible online at URL: http://earth.cecer.army.mil/FF

2 Phase I: Establish Historic Growth Near Fort Knox

To successfully complete the process described herein, data from various sources must be incorporated and manipulated. This integration is key to defining historic trends in urban development and using these trends to forecast future growth.

Previous efforts (Timlin 2002) have taken approaches that are enhanced by technology but rely largely on paper maps. Several advances have occurred that now make possible a more defensible illustration of developmental growth. Significantly, data are much more standardized, so the sharing and manipulation of data are more easily accomplished. The integration of remote sensing (RS) techniques into a single coordinated geographic information system (GIS) framework was critical to this effort. The procedure and components described in this report completely depend on the application and manipulation of advanced computer technologies such as (1) Image Processing (IP) of remotely sensed images, (2) the manipulation of spatially reference data within the framework of a GIS, and (3) the use of commands within a computer scripting language to evaluate the data. The IP used here is the ERDAS software package Imagine (Version 8.4 or later), the GIS is ArcMAP (Version 8.2 or later and/or ArcInfo), and the scripting language is within the Java Runtime Environment (Version 2.0 or later).

Using the capabilities of these software packages, an evaluation of historic and predicted land use growth around Fort Knox was conducted to assess certain "exogenous" factors' impacts on installation mission operations using data from national sources. This study provides a relative measure of land use changes in the immediate perimeter of Fort Knox to provide a consistent visual data analysis of land use change trends that can help installation staff analysts evaluate possible issues or concerns when making potential future alternative mission scenario decisions. For example, an installation with rapid growth in the surrounding land perimeter may have current (or future) constraints for specific types of unit missions. To do this, we turned to two primary data sources that became the backbone of our analysis: the North American Landscape Characterization (NALC) data and the National Land Cover Data (NLCD).

The NALC data source has been collected and analyzed by the U.S. Geological Survey (USGS) using Landsat Multi-Spectral Scanner (MSS) images since 1972. The

NALC project was a collaborative effort between the U.S. Environmental Protection Agency (EPA) and the USGS to provide complete coverage of the contiguous United States and Mexico for the purposes of mapping land cover and land cover change. The NALC project includes Landsat MSS data acquired in 1973, 1986, and 1991, plus or minus 1 year (Figure 1). The USGS has used these images to generate a three-decade series of data (called the NALC Triplicates). These images cover the 1970s, 1980s, and 1990s at 60-m resolution. The specific temporal windows vary for geographic regions based on the seasonal characteristics of the vegetation cover. The NALC triplicate scenes are geographically referenced to a 60- by 60-meter Universal Transverse Mercator (UTM) ground coordinate grid. The NALC project is under the National Aeronautics and Space Administration's (NASA's) Landsat Pathfinder Program.

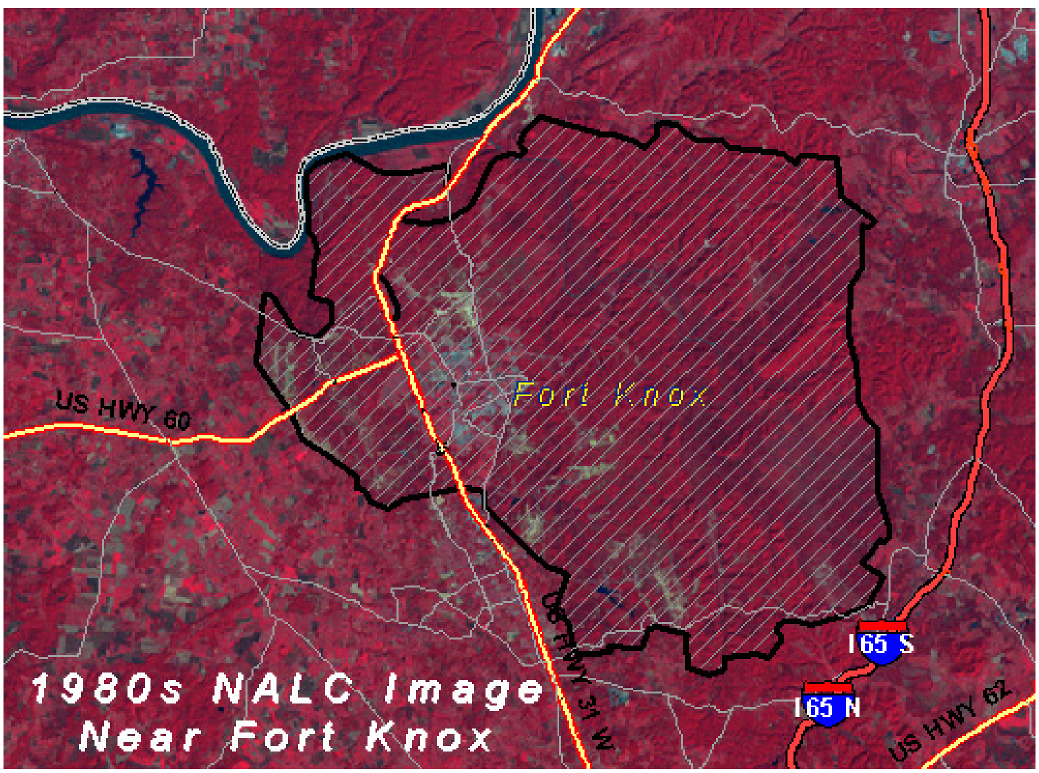

Figure 1. Example of 1980's NALC image with Fort Knox and the surrounding study region.

These data were acquired for the decades of the 1970s, 1980s, and early 1990s. From the data, different land cover types were extracted using standard IP techniques. Land use types that have the potential to affect military missions were separated from the resulting land cover information. Specifically, we were interested in types of residential, commercial, or transportation land uses, as these most often generate incompatibilities with military missions (most often due to the generation of noise, fugitive dust, and light trespass from within the boundaries of the installation). For purposes of encroachment issues at Fort Knox, these "urban" categories, as used by the USGS, are the most relevant to the issues discussed here.

The "ground truth" for the NALC data was determined by comparing its land use categories to those of the NLCD data, the second key dataset used in our analysis. The NLCD project came about due to the high cost of acquiring satellite images. In 1992, several Federal agencies agreed to operate as a consortium in order to appropriate satellite-based, remotely sensed data for their environmental monitoring programs. This group of agencies became know as the Multi-Resolution Land Characteristics Consortium (MRLC) which was responsible for the production of the NLCD dataset, data derived from images acquired by the Landsat Thematic Mapper™ (TM) sensors, as well as a number of ancillary data sources. Original members of the MRLC were the USGS, U.S. EPA, National Oceanic and Atmospheric Administration (NOAA), and the U.S. Forest Service (USFS). Joining the consortium later were NASA and the Bureau of Land Management (BLM).

The NLCD includes the source images and corresponding classifications of land-cover data for specific acquisition dates. This was the first national land-cover data set produced since the early 1970s, effectively replacing older data sets, and has a finer resolution than the NALC, at 30 meters. Data for the contiguous United States circa 1992 (1992 NLCD), which were derived from Landsat-5 TM images (Figure 2), are complete for entire country and are available for download via the World Wide Web at: http://landcover.usgs.gov/natllandcover.html. A description of the data and the classification process has been published in a number of journal articles (Kelly and White 1993; Cowardin et al. 1979; Vogelmann et al. 1998a and b).

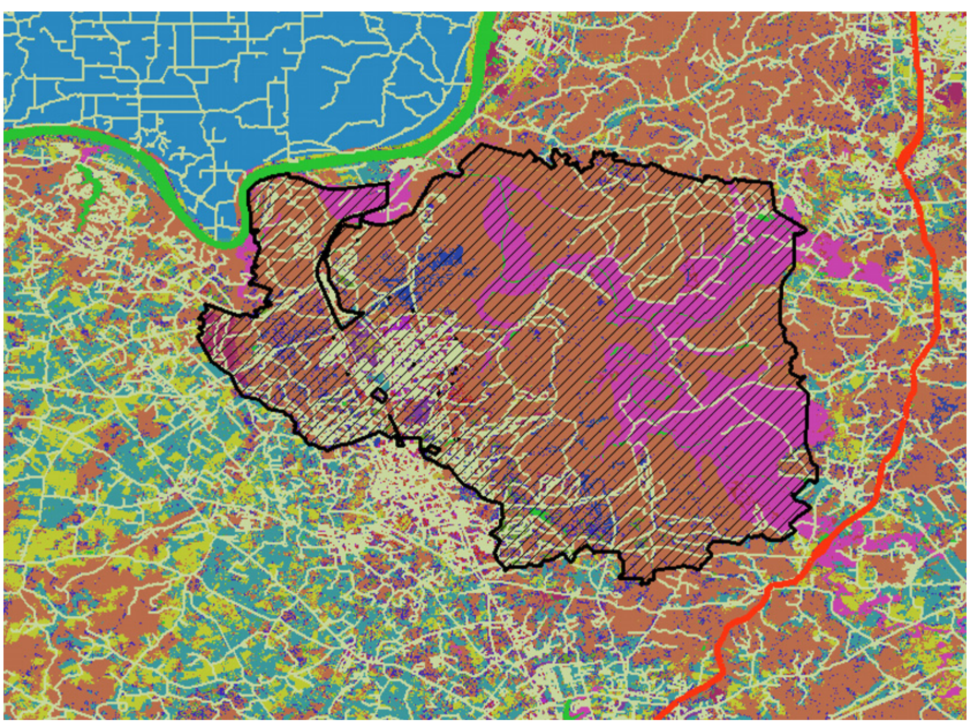

Figure 2. Example map for land uses, as presented in the 2001 NLCD.

The USGS is currently in the process of updating the National Land Cover Data (2001 NLCD) using newly available satellite imagery. This project is ongoing, and only certain portions of the United States are currently available. Fortunately, the entire state of Kentucky has been completed and was available for download when this project began.

The following list is all data available for Fort Knox and the region surrounding the installation, gathered for this project:

Detailed Fort Knox data

Boundary map
Training areas
Impact Areas
Grenade Impact Areas
Ranges and long-term range plan
Flight corridors
Noise contours

General Contextual data

Detailed 1:24,000 USGS Quadrangles (DRGs)
LANDSAT TM: 2 Images (leaf on/leaf off) for 2000-2001 period
30-Meter Multispectral
15-Meter Panchromatic
60-Meter Thermal
30-Meter Topography
LANDSAT MSS images (NALC)
1972
1984
1992
60-Meter Topography
NASA ASTER image for 2000
National Land Cover Data (NLCD) 1992
NLCD 2001

Topography

30 Meter 1:24,000 quads (USGS)
30 Meter Shaded Relief (generated from USGS above)
Detailed 1:24,000 Contour Vectors (from USGS above)
30-Meter Topography (from Landsat above)
60-Meter Topography (from NALC above)
60 Meter Shaded Relief (generated from NALC above)
Digital Elevation Maps (DEMs)

Archival Search from USGS (includes National Imagery and Mapping Agency [NIMA] and National Archives) for hardcopy
Air Photos

State of Kentucky and individual KY county GIS layers

Roads
Highways
Natural Areas
Large, medium, and small municipal area
All available zoning information

The purpose of this research was to combine these data sources and generate a scientifically justifiable set of maps showing how land use changes have occurred over time. In a series of development contracts, ERDC CERL and its partners have developed a procedure to use these images as base data to derive historical land cover maps from the images in the NALC data. This procedure consists of a series of steps using a suite of image-processing GIS manipulations and Java scripts to generate land cover maps for the 1970s, 1980s, and 1990s. The latest version was used to generate map coverage for Fort Knox and the surrounding counties in Kentucky and Indiana. This region served as the study area for this project. Appendix 1 describes the procedure in detail. This effort resulted in a set of spatially explicit graphics that show increasingly intense land usage on the perimeter of the installation.

3 Data Analysis and Historic Encroachment Evaluation

To evaluate the degree of residential and urban growth near the Fort Knox boundary, we developed a method to use easily available, historical data sources (NALC imagery and NLCD data) to show changes in land uses around Fort Knox between 1970 and the mid-1990s. The intent in generating these historic urban land use change maps is to provide data layers that will identify the trend in residential development. We also wanted them to coordinate directly with those being generated in Phase 2, to show future trends in urban expansion around Fort Knox. Combining the two data sets will provide a growth scenario from the past through the present and into the future, a span of roughly half a century. Once accomplished, this will be the first time this has been done, pushing the technology of land use change analysis beyond its current status for the first time.

We developed a procedure and generated products from the NALC and NLCD data to show the changes in "urban" type land uses in the region around Fort Knox. Other land use changes may have occurred during this time frame, such as forest to agricultural area, but if these changes did not represent a switch to urban land use, the differences were ignored. This procedure was similar to that developed and used in a previous study carried out at ERDC/CERL. Using standard spatial software packages (ESRI ArcGIS and Leica Imagine), the developed procedure uses the NALC imagery to characterize the historic land uses in the region. An unsupervised classification provided the input for the characterization. Additional steps were developed to interpret this raw data. The procedure resulted in an indication of the historic land uses that have the potential to restrict or impact the military training and testing activities occurring within the installation. Restrictions will depend on the type of training and testing activities present.

Analysis of Historical Urbanization from LANDSAT Imagery

Based on the procedure, each decade of the unsupervised imagery was classified as indicated in Table 1.

Table 1. Urban determination for different classes in Unsupervised Classifications.

	1970	1980	1990
Category			
1	Urban	Urban	Urban
2	Urban	Urban	Urban
3	Urban	Urban	Urban
4	Urban	Urban	Urban
5	Not Urban	Urban	Urban
6	Not Urban	Urban	Urban
7	Not Urban	Urban	Urban
8	Not Urban	Urban	Urban
9	Not Urban	Not Urban	Urban
10	Not Urban	Not Urban	Urban
11	Not Urban	Not Urban	Urban
12	Not Urban	Not Urban	Not Urban
13	Not Urban	Not Urban	Not Urban
14	Not Urban	Not Urban	Not Urban
15	Not Urban	Not Urban	Not Urban
16	Urban	Not Urban	Not Urban

Based on this distribution of categories, the resulting allocation of urban lands and trend over time is presented in Figure 3 and Table 2. At the regional scale, it is difficult to perceive the degree of development that is occurring because the white areas easily overpower the details showing the slow, step-by-step progress of development. It is much easier to visualize this progress by animating the images from each decade. This has been done in the form of a Microsoft™ Power Point presentation, which accompanies this document. Click this link to view the presentation: Full Study Area Urban Expansion.ppt. The referenced presentation integrates the USGS NLCD urban categories for the year 2001 so that the entire sequence covers roughly four decades. From these data, it is clear that a good deal of development is occurring within the region. One of the major centers of development outside the Louisville area is adjacent to the Fort Knox perimeter in what is called the Radcliff-Elizabethtown region. A more detailed view of this part of the study area can be viewed here: Study Area Detail.ppt

Table 2. Summary of growth in urbanization from 1972 -2001 derived from NALC and NLCD data.

Year	Years Since Beginning	Cell size (sq mtr)	# Non Urbanized Cells	# Urbanized Cells	Total number of Cells	% Urbanized
1972	0	28	10612127	147554	10759681	1.37%
1982	10	28	10390358	369323	10759681	3.43%
1992	20	28	10261533	498148	10759681	4.63%
2001	29	27.25	10329553	723267	11052820	6.54%

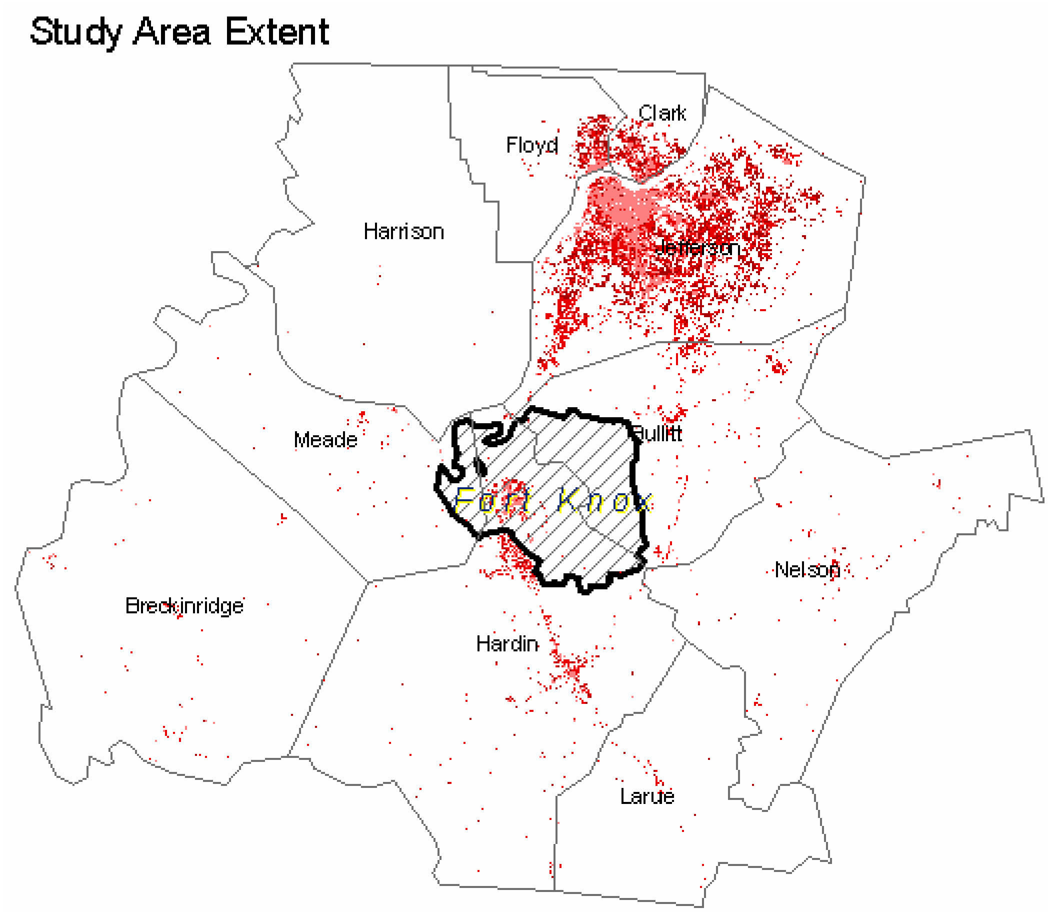

Figure 3. Increasing Urban Land Uses 1972-1992; darker reds are more recent Urban Land Uses.

Charting the growth in the region result in the trend illustrated in Figure 4.

This figure shows a straight-line growth pattern for the region. The straight-line equation that can be derived from this trend is:

Y = aX + b

%Urbanized = a(years since 1972) + 1.37

a=Y/X - 1.37

a=(%Urbanized-1.37)/(years since 1972)

a=0.18%

Therefore, knowing the % Urbanized for a region within the study area, we can calculate the date that this projection represents by the following equation.

Date of Projection =

= (%Urbanized-1.37)/ 0.18 +1972

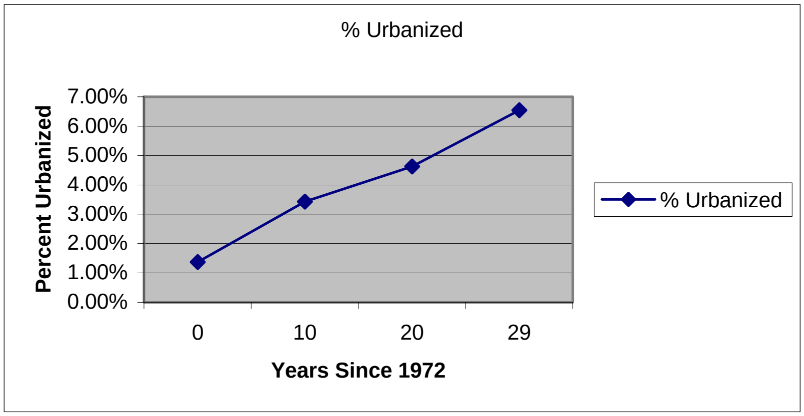

Figure 4. Growth curve in the years from 1972-2001.

Working backward with the original data, this equation is accurate to within 2 years, with an average residual of zero (Table 3).

Table 3. Percent urbanization from 1972-2001.

Year	Backward calculated year	% Urbanized	Calculation Residuals (Years)
1972	1972	1.37%	0
1982	1983	3.43%	1
1992	1990	4.63%	-2
2001	2001	6.54%	0

Very roughly, the region has been adding 2% developed land every recent decade.

For the area near Fort Knox, Figure 5 shows the resulting development in the Radcliff-Elizabethtown urbanized area on the southwest edge of the installation. Once again, the accompanying Power Point presentation illustrates the growth in this locale more clearly.

Analysis of Area Within a 1- and 5-mile Buffer of Fort Knox

When examining Fort Knox as a part of the overall region, the effects of recent land use change trends on the installation may become attenuated. Narrowing the scope of our focus to the area directly adjacent to Fort Knox yields a clearer picture of those effects. The following analyses pertain to areas defined by 5-mile and 1-mile buffers around the installation's perimeter. Figure 6 shows historic urbanization near Fort Knox within the 1- and 5-mile buffers. An analysis was done on the distributions presented in Figure 6. The results are shown in Table 4.

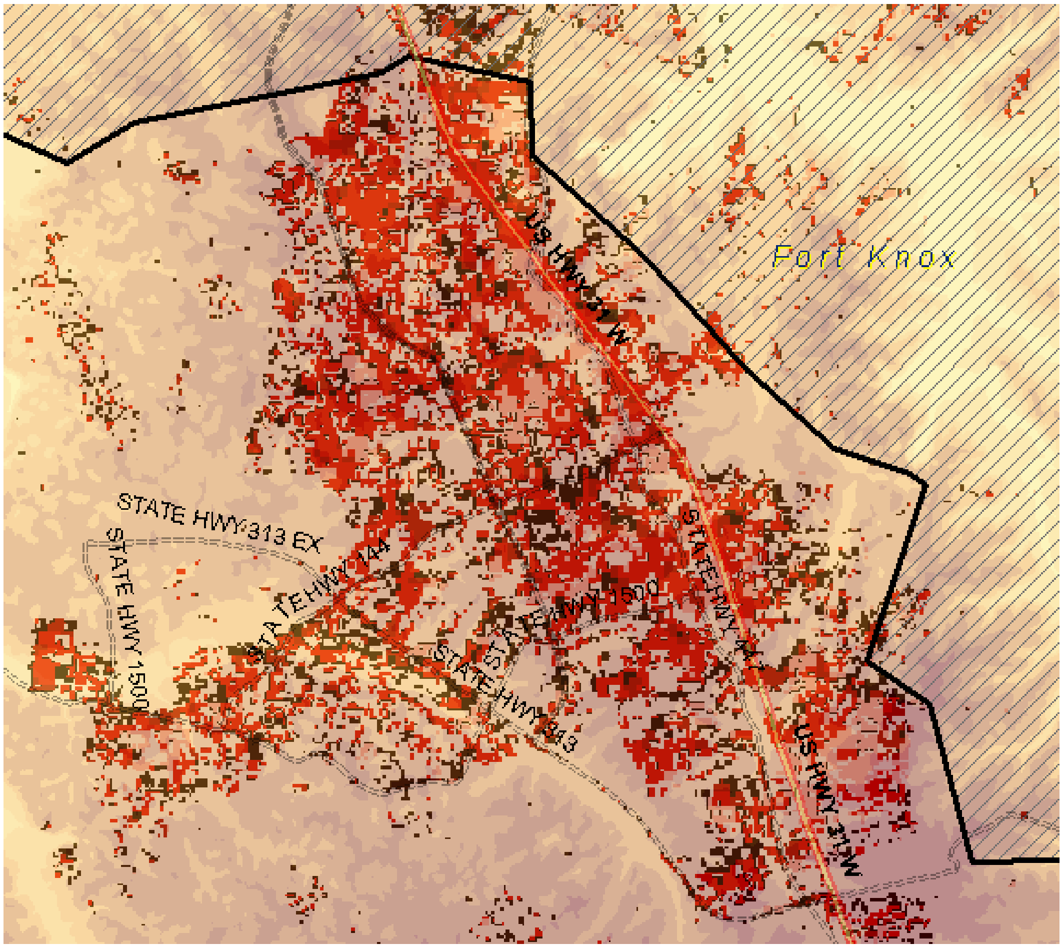

Figure 5. Recent urbanization near Fort Knox. Lightest red is the built area in the early 1970s; more recent development is darker red, overlaid on a relief map.

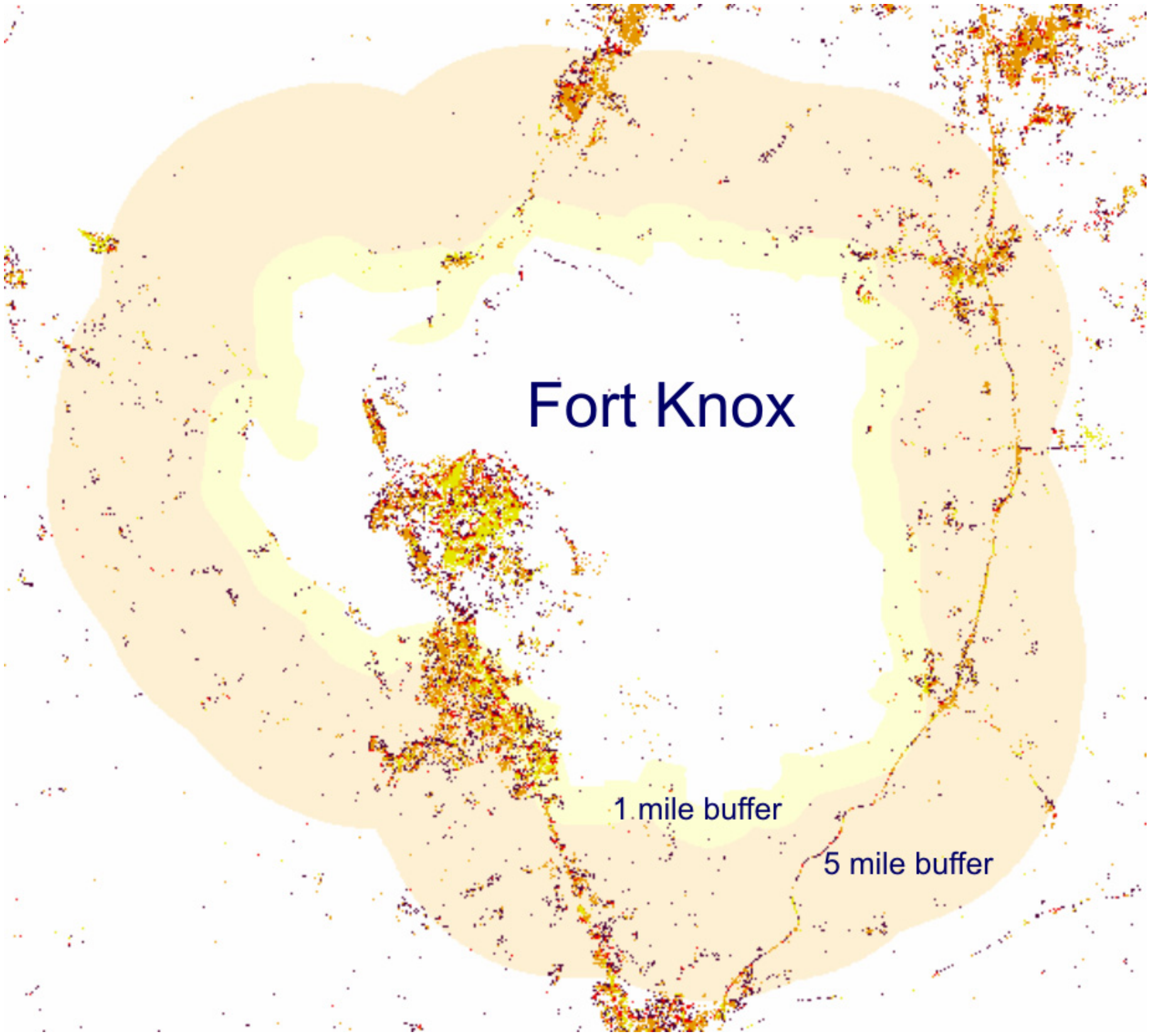

Figure 6. One- and 5-mile buffer around Fort Knox with historic urbanization trend from 1972 (lighter color) to 2001 (darker color).

Table 4. Urbanization near Fort Knox over 30-year period (1972-2001).

Buffer Analysis							
	Urban Pixels of Concern in			Total Pixels in			
Concern	0-1 mile buffer	0-5 mile buffer	Not urban	1 mile buffer	5 mile buffer	% Urban in 1 mile	% Urban in 5 mile
urb70_iclass	2,347	5,651	1,025,435	186,829	1,031,086	1.3	0.5
urb80_iclass	7,985	27,696	1,003,390	186,829	1,031,086	4.3	2.7
urb90_iclass	7,227	24,203	1,006,883	186,829	1,031,086	3.9	2.3
urb00_iclass	11,885	45,379	985,707	186,829	1,031,086	6.4	4.4

From Table 4, a summary graph can be generated as shown in Figure 7.

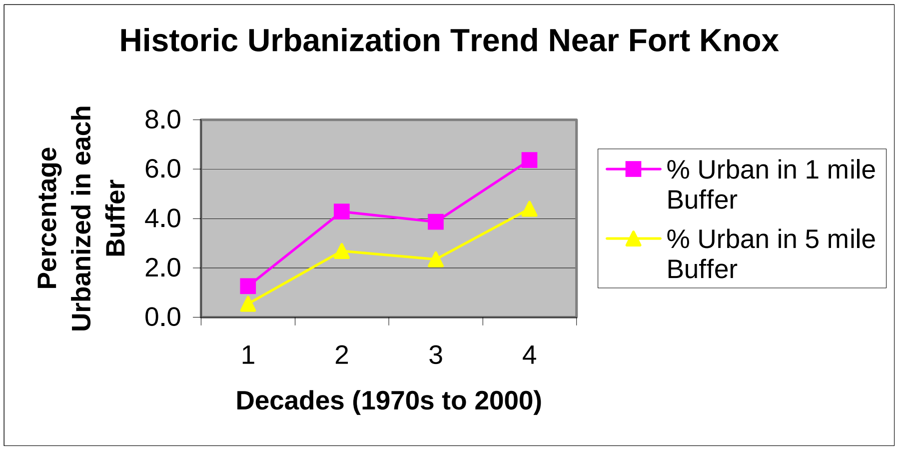

Figure 7. Historic urbanization trend near Fort Knox.

From this series of analyses, we determined that the trends near the installation are similar to those of the entire region.

- The trend occurring in the 1-mile buffer more closely reflects the regional development history than that observed within the 5-mile buffer. (Between 1980 and 1990, there was a noticeable decrease in development within 5 miles of the installation)
- The regional trend also shows a slowing of the urbanization rate between 1980 and 1990, but it is not as pronounced as it was nearer the Fort Knox boundary.
- Since 1990, growth has accelerated dramatically (i.e., the slowed growth in the1980s was an anomaly in an otherwise continuing urbanization trend.)
- The urbanization trend within 1 mile of the Fort has always been greater than that within 5 miles of its boundary (i.e., the area directly adjacent to Fort Knox attracts more urbanization than places further away).
- Urbanization near Fort Knox is increasing at a faster rate than the nearby region. (For example, in 1970 the difference in the rates was 0.8%, but in 2000 it was 2.0%. The rate difference more than doubled in 30 years.)

Historic Analysis Summary

The analyses of the historic data we were able to obtain for this area, and the statistics derived from those analyses, resulted in the following observations:

1. Urbanization is quickly occurring throughout the study area.
2. Current urbanized areas and road networks provide nuclei to attract more development
3. In the past, development was dispersed.
4. More recent trends show a greater concentration of development

5. This concentrated development is occurring right up against Fort Knox's boundary.
6. The areas most sensitive to development are:
    - Radcliff-Elizabethtown region in Hardin County
    - Muldraugh City area within Fort Knox in Hardin County
    - The Northeast Fort Knox corner near Shepherdsville in Bullitt County
    - Southern Bullitt County near Lebanon Junction
    - North Fort Knox along US Route 31.

4 Emerging Issues Dealing With the Use of High-Resolution Satellite and Aerial Photography

The use of digital satellite imagery and the techniques used to analyze it have been developing for about 35 years. Each generation of satellite imaging technology provides higher resolution images than the one before. This higher resolution makes pattern (or feature) recognition more important now than it has been in the past. Yet the digital data extraction technology has not kept pace with the advances in data resolution.

The gross resolution of the original imaging satellites was far less than those using today's technology. Landsat 1, for instance, had a resolution of 80 m on an edge. This meant that the analysis of the spectral band data from Landsat 1's imagery took priority over the recognition of the spatial patterns because, at this gross resolution, patterns were blurred out or smeared. This meant spectral analysis provided the greatest benefit for generating classifications, particularly land use/land cover classifications.

With the emergence of digital imagery resolution in the range of 1 m, a major paradigm shift has occurred. At a resolution of approximately 3 to 5 m, spectral resolution becomes less important than pattern recognition. The human eye is very good at pattern recognition, but digital techniques for pattern recognition are significantly lagging behind those of the traditional spectral techniques so useful for imagery at grosser resolutions. In fact, for this project, the staff of Fort Knox provided imagery available for the installation at 0.3 m. However, almost all of the analysis done for this project was with imagery at either 30- or 16-m resolution; a full order of magnitude or more difference.

Problems emerge at these new higher resolutions due to the fact that, at finer resolutions, objects stand out as separate entities rather than congregated smears of spectral signatures. But having a spectral smear has its advantages. For example, when you analyze a forest, the portion of trees in the shadows or shade has an entirely different spectral response than those in the bright sunlight. At 30-m resolution, this difference is smeared out, but at about 5-m resolution, a spectral analysis will show the shaded portion of a tree as highly dissimilar to the sunlit portion of the same tree and these will be classified as two entirely different objects. The high-resolution imagery that is now available at Fort Knox often makes it difficult for the computer to combine objects that we intuitively know should be in a single category (urban). Yet the ability of the human eye to recognize and categorize these same objects is very good. Therefore, humans tend to have little sympathy for the difficulty of dealing with digital pattern recognition.

For the purpose of urbanization issues, high-resolution imagery presents another problem. Although it is easy to recognize where buildings are visually, and even digitally, when it comes to urbanization, we really wish to know how much land is in urban use. This parameter has a much greater extent than the building's footprint on the landscape. In other words, even if we recognize that buildings exist, this still does not tell us much about how the land, or the parcels upon which the buildings reside, are set aside for what we would call urban purposes. So, even if we have the digital ability to recognize buildings as easily as the human eye can, that would not give us the answer to how much of the landscape has an urban land use. Once again there is an advantage to having the imagery smeared. Smeared imagery better represents the proportion of land which has a spectral response that is urban, usually consisting of a combination of trees, concrete, and rooftops. In high-resolution imagery, these three elements are separated. When this occurs, the categories of rooftops probably cannot be separated from gravel pits and bare ground. Similarly, trees in someone's backyard cannot be separated from forest trees. So, in terms of urbanization studies, by applying classical spectral techniques to the high-resolution imagery, you have lost information instead of gaining it.

The Current State-of-the-Art of Imagery Pattern Recognition

It is very clear that high-resolution imagery is the trend for the future. So what is the state of the art for pattern recognition in GISs? For the most popular GIS, ESRI's ArcGIS, there is little capability in dealing with pattern recognition in spite of the fact that this software package is recognized as leading in GIS vector (consisting of lines, points, and polygons) analysis capabilities. The ArcGIS help section has two references for "feature extract" and "pattern recognition," both of which deal with raster neighborhood analysis. Neighborhood analysis is not the pattern recognition capability we need.

With this in perspective, we need to focus on the fact that the imagery we have to deal with is inherently in raster format (consisting of individual pixels, or grid cells). ESRI tends to emphasize its vector capabilities more than its capacity to handle raster imagery, so it is not likely that ESRI will deal with the issue soon. To investigate the issue further, the ESRI ArcGIS user support web site was searched.

This issue was addressed in only a single user discussion group in September 2000 (per the annotated discussion below). Although the search found 24 pattern recognition discussion topics, all of the others dealt with the ability to recognize an ellipse; not a useful capability when trying to do pattern recognition for rectangular buildings.

> ESRI-L] SUM: Image feature extraction algorithms -- Sep 22 2000
> Dear List:
> Sorry for my much delayed sum. My original inquiry was for information pertaining to linear feature extraction and pattern recognition and in particular what software applications and especially other algorithms people are using to extract features (linear and other) from satellite imagery.
>
> Below is a list of webpages/articles/hints/etc. which I have received. A large thanks to all who replied!!
>
> Neil Malcolm
> Graduate Student
> School of Planning
> University of Waterloo
> http://www.fes.uwaterloo.ca/u/nwmalcol/index.html
>
> ---
> Responses -->
>
> **1) Canny's algorithm:**
> http://www.cs.cmu.edu/~vaschelp/Imageview/Vista/vista-help.html
> http://www.cs.ubc.ca/nest/lci/vista/vista.html
>
> **This site is no longer available; it is now a part of:**
> http://vasc.ri.cmu.edu/old_help/Imageview/Vista/vista-help.html#overview
> *"Vista is a software environment for processing images, edge sets and arbitrary data vector sets in an object oriented framework. It handles every conceivable type of image format including sequences, arbitrary bands and floating point pixel values for example. The library uses a very nice data storage format that can contain arbitrary lists of objects with arbitrary user defined attributes. Postscript conversion is available. Locally, we have converters from GIL and many other formats. Other hilites: command line argument parsing, a simple set of routines for developing Xwindows graphical interface, a Tcl/Tk widget (locally developed) for displaying Vista images."*

The referenced page gives an example of a Canny algorithm, though on an image, not within a GIS framework.

2) Articles:

Bert Guindon, A Framework for the Development and Assessment of Object Recognition Modules from High-Resolution Satellite Images, Canadian journal of Remote Sensing, August 2000, Vol. 26, No. 4, pp. 334-348.

Wei Li et al., Watershed-based hierarchical SAR image segmentation, Int. J. Remote Sensing, 1999, Vol. 20, No. 17, pp. 3377-3390.

B.S. Daya et al., Morphological operators to extract channel networks from digital elevation models, Int. J. Remote Sensing, 2000, Vol. 21, No. 1, pp. 21-29.

3) FeatureFinder available from Innovative

Solutions Group (ISG) in Sterling, VA
http://www.isgtech.com

There are no longer any references to FeatureFinder at the ISGTech web site. A search of their site also revealed no hits for the various combinations of the key words: “Pattern Recognition” and “Feature extraction.”

4) TNT Mips (http://www.microimages.com).

You can download the "lite" version for free.
“Since 1986, MicroImages, Inc. has been providing the most advanced software in the industry for GIS, desktop cartography, image processing, and geospatial analysis.

The TNT products support fully integrated GIS, image processing, CAD, TIN, desktop cartography, and geospatial database management. With TNT, you edit, display, and present project materials in raster, vector, CAD, relational database, and TIN formats.”

A search of the MicroImages website pattern recognition capabilities indicate that their reference is to Optical Character Recognition (OCR) and handwriting pattern recognition, but there are no references to data extraction from aerial photography/satellite images. Most references are to their 1974 theoretical source document: Tou, Julius T. and Gonzales, Raphael C. (1974). Pattern Recognition Principles. Reading, MA: Addison-Wessley.

5) Erdas's Imagine 8.4 --> Not free.

Since the Imagine software was available, we investigated further the reference to the Imagine pattern recognition capability.

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Pattern Recognition. Pattern recognition is the science—and art—of finding meaningful patterns in data, which can be extracted through classification. By spatially and spectrally enhancing an image, pattern recognition can be performed with the human eye; the human brain automatically sorts certain textures and colors into categories. In a computer system, spectral pattern recognition can be more scientific. Statistics are derived from the spectral characteristics of all pixels in an image. Then, the pixels are sorted based on mathematical criteria. The classification process breaks down into two parts: training and classifying (using a decision rule).

Although their definition refers to both spectral and spatial pattern recognition, further investigation revealed that their software deals only with the issue of spectral recognition; spatial recognition is left to be done by the human eye.

Thus, for both of the major GIS packages available, there is no pattern recognition capability useful for the purposes of extracting urbanization trends. However, the GRASS GIS program, a free public domain GIS, does have some beginning feature recognition capabilities (the *i.zc* tool can be used with the Fourier transformation commands for simple analyses).

Approach for an Application to the New Paradigm

Suppose the scripts that support pattern recognition existed in one of the basic GIS packages. A critical capability would be to recognize right angles, linear features and rectangles. Since straight lines and right angles are indicative of human construction activities (in particular, building edges and road edges), what would be the methodology to determine urban areas? It could be very simple such as, "If the number of right angles within an area of a particular size is greater than some threshold, then urban." If you wanted to distinguish between areas which were set aside for large business buildings and warehouses (that is the category of urban commercial) then an additional category could be generated from the statement, "If the number of rectangles of a size greater than a particular number of square meters within an area of a particular size is greater than a threshold, then commercial urban." Of course, by these methods, one would be recognizing a location larger than a building as an urban location. The next step would be to congregate areas of high-density urban as urban and remove areas (raster cells) with few urban occurrences as exceptions (e.g., large implement sheds or barns in rural areas).

Since the availability of high-resolution imagery, like the 0.3 m resolution imagery we looked at for Fort Knox, is expected to become more common, future research needs to address the issue of pattern recognition analysis. The next section of this report represents work done to mitigate the need for better pattern recognition software for high resolution GIS imagery.

5 Initial Investigation Into Alternative Technique To Generate Historical and Current Urban Land-Use Maps and Trends

Although versions of the techniques used and described in previous sections of this report are widely accepted as a means of determining land use changes over large regions, they suffer from several limitations:

- **Cost:** It requires expensive satellite imagery that then must be analyzed in a labor-intensive manner by a highly paid Image Processing and GIS expert.
- **Infrequent Baseline:** This process depends on the baseline NLCD data being available. Currently, only one complete NLCD exists (circa 1992), while the second (circa 2001) is slowly being generated. Although for this project we were fortunate enough to acquire one of the few 2001 NLCDs currently available, this is not the case for much of the country. Further, there is no guarantee that this critical dataset will be completed for 2001 or for any other time in the future.
- **Lack of Current Data:** The NLCD data sets are generated once a decade (maybe) for a time near the beginning of the decade. This report is being written halfway through one such decade. We have no way of knowing what recent changes have occurred, but these are the changes that may have the greatest impact on military missions. This situation will deteriorate for the rest of the decade and well beyond into ~2015.
- **Inability To Detect Urbanization Directly:** The NLCD (and the imagery from which it is generated) do not directly measure our major concern: urbanization. Imagery from the LANDSAT TM (and similar satellites) measure reflectance. We hope an expert can extract urban features and distinguish them from non-urban areas using this reflectance, but to measure urbanization, we generally measure and/or extract the reflectance of concrete roads and gravel roofs. The problem is that concrete and gravel on roofs have the same spectral reflectance characteristics as barren rock and desert pavement, and sometimes of barren soils and snow-covered ground.
- **Uncertainty:** In each image, every pixel examined represents a number of objects that contribute to its color signature. Often this is a combination of concrete and trees in a yard, or worse, concrete and forest. So, is the pixel urban or natural? It is not possible to determine with certainty the content

of a mixed pixel and almost all pixels are mixed. This problem is well illustrated, even in our baseline data – the USGS NLCD dataset. So how reliable is our baseline?

For these reasons, it is suggested that multi-spectral imagery is not a great measure of urbanization. In a recent report on light pollution concerns to military training and Threatened and Endangered Species (TES) management (Lozar and Schneider 2005), an alternative was suggested. Another option is to use nighttime satellite imagery to show where lights occur, because night lighting is a very good indicator of human activity (Elvidge 2005). This imagery has the potential to assist Fort Knox in monitoring civilian encroachment around the installation's perimeter, and may also be helpful in assessing light pollution emanating from urban areas off post. This civilian light pollution has the potential to affect night training exercises occurring in Fort Knox training areas.

The Defense Meteorological Satellite Program (DMSP) operates three satellites carrying the Operational Linescan System (OLS) in low-altitude polar orbits to record nighttime data:
(< HYPERLINK "http://dmsp.ngdc.noaa.gov/html/%20sensors/doc_ols.html" >). The DMSP-OLS has the unique capability to detect low levels of visible-near infrared (VNIR) radiance at night. With the OLS "VIS" band data, it is possible to detect clouds illuminated by moonlight, plus lights from cities, towns, industrial sites, gas flares, and ephemeral events such as fires and lightning-illuminated clouds. Each of four satellites cover the entire earth once every night, so currently all locations on earth are sensed four times every night. DMSP data are down-linked to Thule Air Force Base, refined and transmitted to the National Geophysical Data Center (NGDC). Currently, NGDC receives and processes approximately 8.5 GB of data per day.

From the raw DMSP images, NOAA has created a series of global coverage datasets called the Lights at Night dataset. It is derived from the visible band of the DMSP satellites. Summing the observations made on many orbits creates the dataset; even very faint stable light sources are identified. The first Nighttime Lights of the World dataset is compiled from mid-1992 and 1993. DMSP nighttime data are collected when moonlight is low. Using the OLS thermal infrared band, areas containing clouds were removed and the remaining area used in the time series. Since the original data were created, more have been produced. The original was refined and published, covering the period October 1994 – March 1995. A new survey for the year 2000 was completed using the DMSP data.

Using the night light data has advantages as follows:

- **Inexpensive:** Anyone can download the available refined data set for the entire world for free. Individual archival images can also be ordered and downloaded.
- **Frequent Baseline:** The refined data sets for the entire world have been generated at about a 6-year interval. For a specific region, individual images are acquired four times a day. Since this data is primarily for military (national security) applications, it is very likely DMSP imagery will be available into the future.
- **Timely data:** For a specific region, individual images are acquired four times a day.
- **Direct detection of urban area:** In the United States, light at night is almost always related to human urbanization (Sutton 1997). Only a few exceptions (like a forest fire) exist and when these occur, they are easy to remove.
- **Certainty:** Animals do not make light at night. In an image where there is a luminance signal, one can measure human activity intensity. In addition, the DMSP satellites are very sensitive, even to a low level of illumination. If a reasonable amount of light is reflected, it is very likely to be detected.
- **Change can me measured:** Since the amount of light at a specific location is measured as a level on a digital scale, the degree of change can be evaluated over time, as opposed to simply determining if a change has occurred.

There is one drawback:

- Resolution: The sensor collects data at 1-kilometer resolution. Since it is a global coverage program, higher resolution is not expected to materialize soon, but for regional planning purposes, this may not be a significant concern.

For these reasons, an initial feasibility evaluation of the DMSP data was carried out for this project. This consisted of:

- Showing the current data near Fort Knox
- Comparing the Light data with the NLCD data.
- Using the data to determine trends and projections numerically.
- Acquiring current regional imagery (for around 7 pm on a winter's evening).

Analysis of Current Data Near Fort Knox

The distribution of night lights near Fort Knox is shown in Figure 8.

From this data, we wanted to determine:

- How closely is only the urban category reflected in the night-lights data? (A restrictive analysis.)
- How inclusive is the night-lights data of urban categories? (An inclusive analysis.)

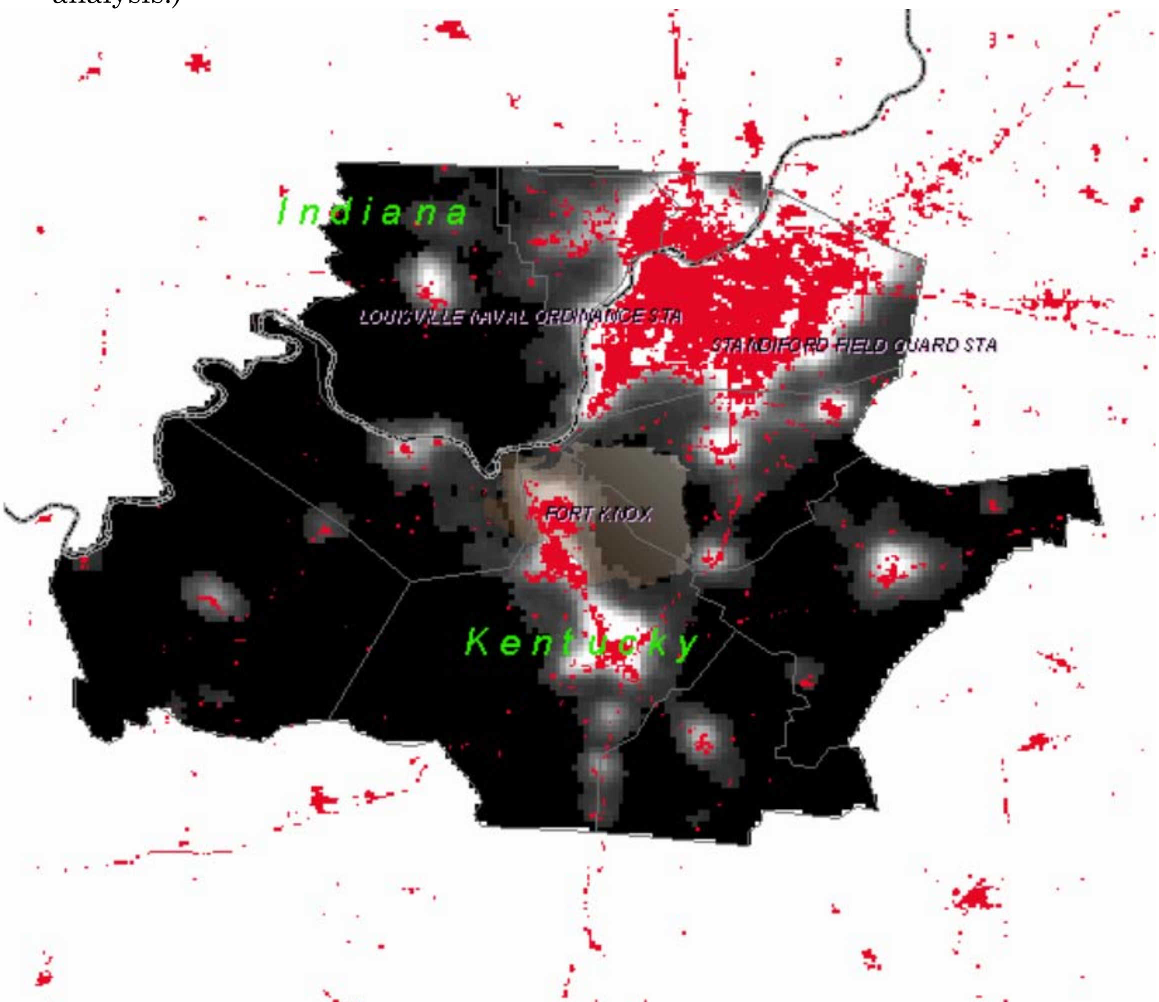

Figure 8. 2000 Night Lights image within study area. USGS 2001 urban categories are overlaid in red.

To begin to answer the first question, we looked at those areas that the USGS data categorized as urban (for the year 2000). Within this restrictive area of analysis then, what are the distribution and the intensity of the night-lights? The most desirable result here would be to have a high count of urban areas pixels correspond to bright night-light values and a lower count in areas of dim night-light values. The visual representation of the urban/night-light map is shown in Figure 9. In this figure, the most desirable result would be to see a great deal of white bordered by some gray. What we see are the white concentrations bordered by gray, but we also see a good deal of black (i.e., night-lights data indicate little urbanization). Graphing the distribution in a chart form (Figure 10) represents this distribution well.

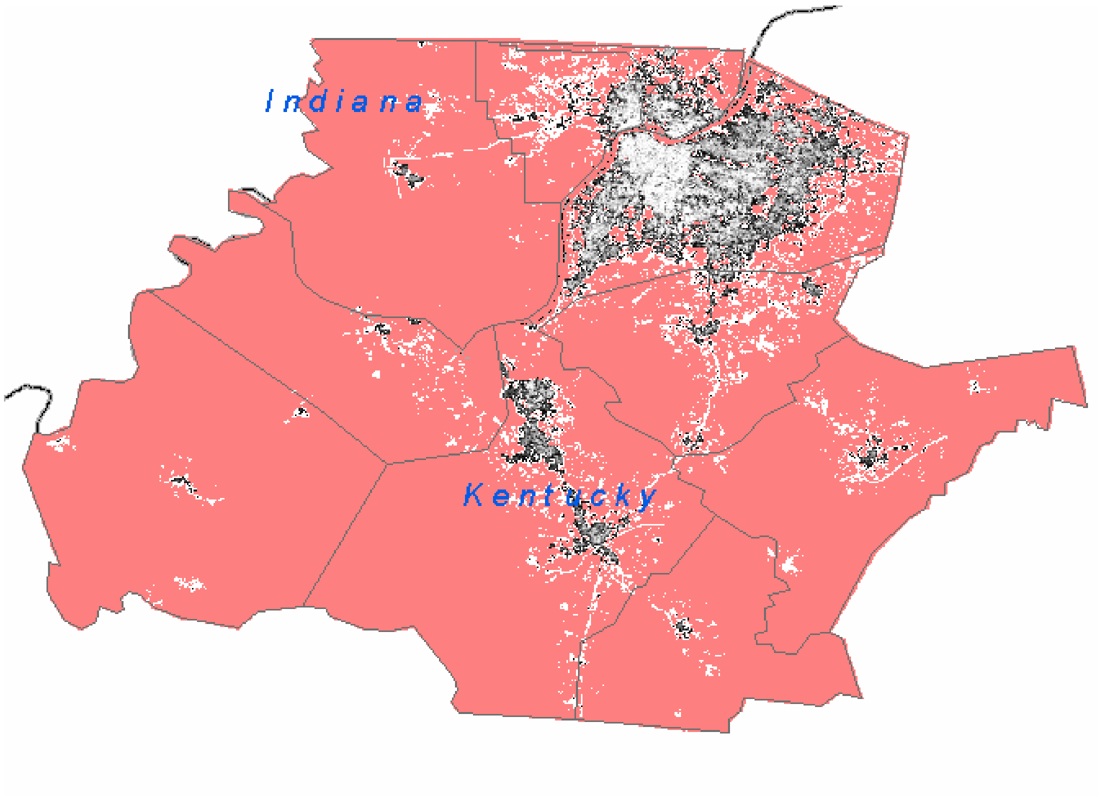

Figure 9. Night-light intensity only in areas defined by USGS as an Urban Category (salmon color covers excluded areas).

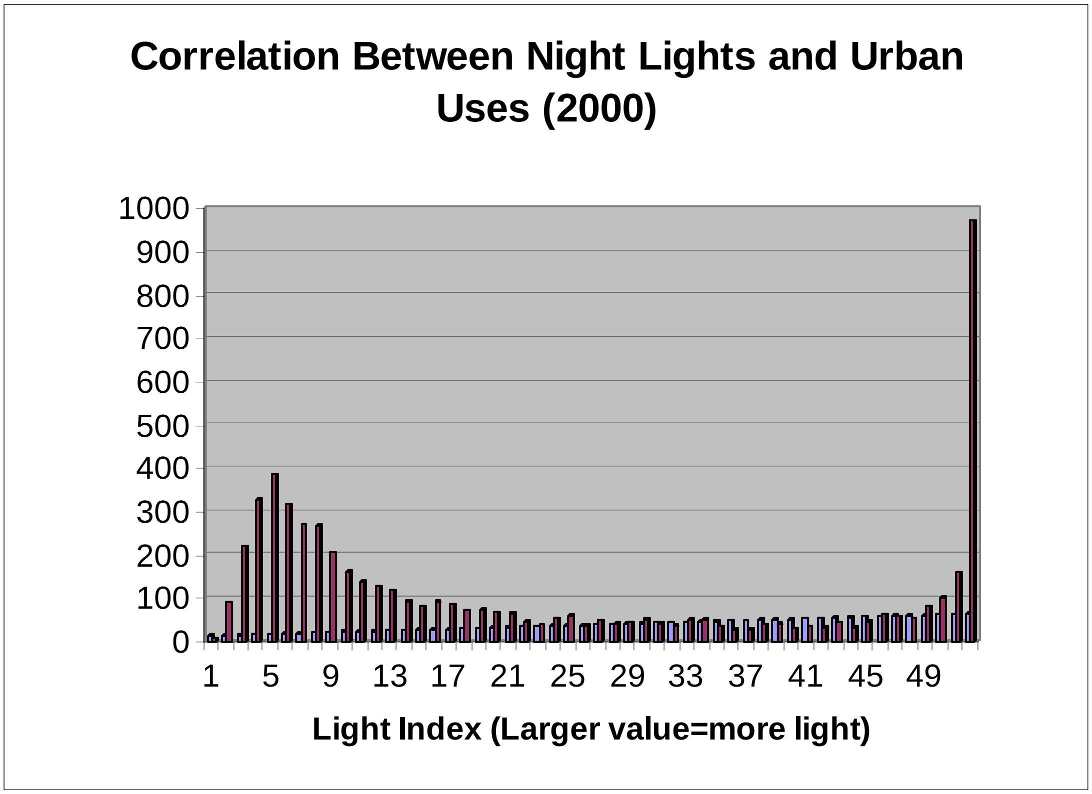

Figure 10. Night lights versus urbanized land uses (2000).

There was a large, anomalous distribution of occurrences of the lower values. This was greater than we expected. A large peak for the highest night-light intensity values was detected on the other end of the distribution, indicating that highly urban areas are well captured. It should be mentioned here that the DMSP sensor is so receptive that at high intensities it becomes saturated. Therefore, all locations of the highest intensities are clumped into the top DMSP category. In other words, that top category clumps together many very highly lighted areas. Therefore, the fact that the graph jumps at the end was expected, considering the limitations of the sensor.

Thus, in answer to question 1, we have a mixed result: the data seems to well capture highly urban areas but gives potentially misleading results at low light intensity locations.

To answer the second question, we reversed the procedure by using the night-lights data as a mask. This enabled us to see how much of the urbanized area is captured within that data. We used the resolution of the night-lights data and divided the categories into four possibilities. The result can be seen in Figure 11. From this data, we were hoping to see all urban land uses within the lighted areas. Table 5 shows the actual statistics for this map.

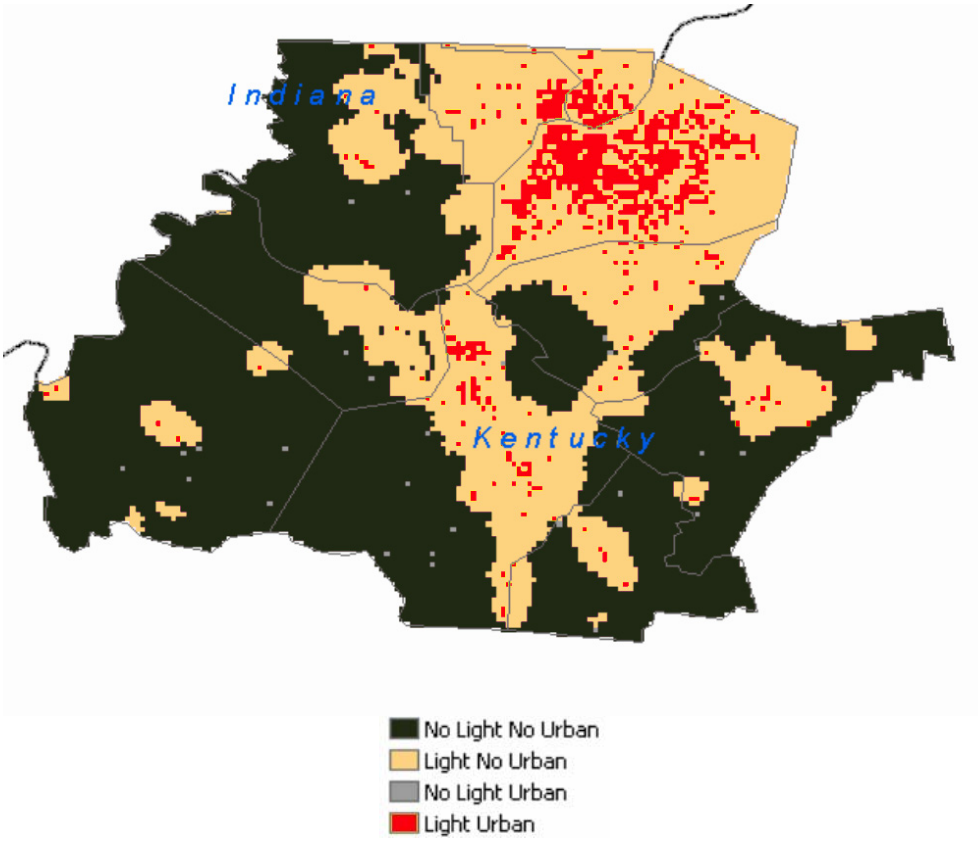

Figure 11. The universe of the study area classified into four possibilities.

Table 5. Percentage distribution of Figure 10.

Description	Count	Percent
No Light No Urban	8091	59
Light No Urban	4890	35
No Light Urban	27	0
Light Urban	806	6
Totals	13814	100

In fact, this table presents the most desirable result — if an area is not urban, it will be correctly identified as so and, if it is urban, it will be accurately identified as well. Further, the error category of urban areas without light is less than 1 percent. Since this is an inclusive analysis, the area of light and no urban is great but cannot be considered a mistake in the sense presented here. Since light spreads, it can be expected that the night-light maps will always show an area more extensive than the actual urbanization they reflect.

However, suppose one feels that category "Light No Urban" would better reflect the situation. In the "Data Analysis and Historic Encroachment Evaluation" section of this report, we found that the urban areas covered about 6% of the land in the study area. This then is the target for this analysis. In fact, the light and urban coverage from the above table is 6%.

From the analysis for the first question, we can see that the night-light values of less than 22 poorly reflect the existing situation. The analysis was done again using a mask where the cut off point is 21 rather than 0 as above. In so doing, we arrive at Figure 12 and Table 6.

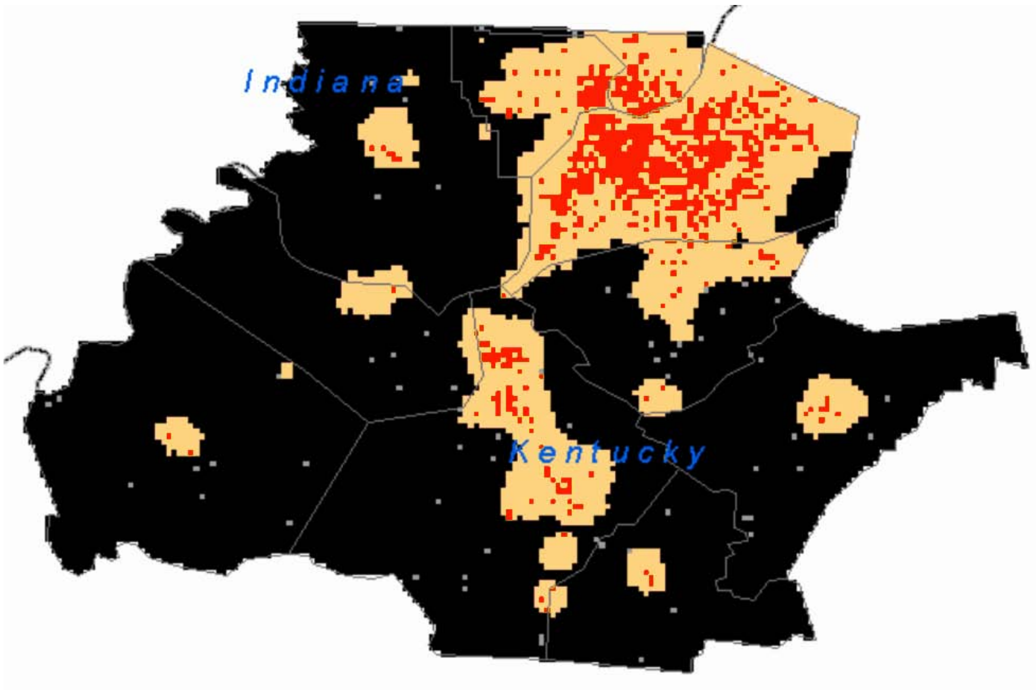

Figure 12. Better results can be obtained by setting a higher tolerance on the urban light intensity levels.

Table 6. Better results can be obtained by setting a higher tolerance on the urban light intensity levels.

Description	Count	Percent	Error Analysis
No Light No Urban	10299	75	0
Light No Urban	2682	19	19
No Light Urban	63	0	0
Light Urban	770	6	0
Total	13814	100	19

By this technique, we have increased the accuracy of the Light/No Urban category (by 16%). Following on, we should be able to find a very accurate fit with the night-light cut off at about the intensity value of 50. At this point, we have slightly decreased the correct identification of urban areas although we have increased the accuracy of the Light/No Urban category by another 12%.

We were able to decrease the overall error by greater than half. But at the same time we increased the error in our most critical data point, Light/Urban. So the question to be asked was: Which is most important?

- To be accurate on the urban areas or

- To be accurate on all the possibilities

Since we were looking for urbanized areas, we suggest that the former is the more desirable situation. We submit that the map resulting in each of these steps supports this choice. On inspection, one can see that, although the simpler map in Figure 13 and Table 7 shows a lower Error Analysis Total, it also misses areas of urbanization that are preserved in Figure 12. In dealing with a trend analysis, these smaller new and edge areas really represent where the changes are occurring, so we would not want to lose them.

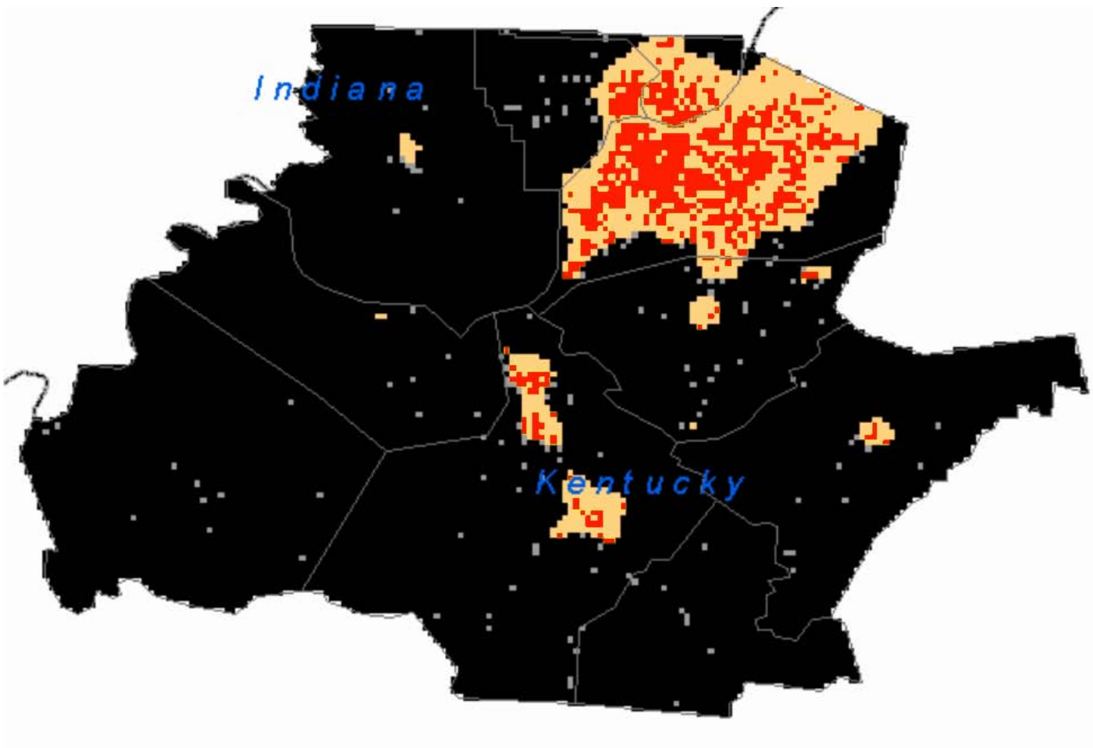

Figure 13. Higher tolerance also begins to decrease correct answer percentages.

Table 7. A higher tolerance also begins to decrease correct answer percentages.

Description	Count	Percent	Error Analysis
No Light No Urban	11971	87	0
Light No Urban	1010	7	7
No Light Urban	148	1	1
Light Urban	685	5	1
Total	13814	100	9

The conclusion from analysis method 2 is that the night-lights images are a very good indicator of urbanization. They are reliable in showing urban areas and non-urban areas with a very high degree of accuracy. This method shows a high tolerance for correctly identifying urban areas. For the study area near Fort Knox, a light level cut off in the range of 21 will show urban and urbanizing areas well and even doubling this value only slightly decreases the correct identification while dramatically decreases overall error. It is suggested that correct identification should be the priority over decreased overall error because this better preserves the spatial distribution of urban developments.

Updating Images for More Recent Data

As previously mentioned, one of the advantages of the DMSP data is that it is available continuously, every night. Since we are halfway through the first decade of the 21st century, it would be nice to get current data. In fact, this data is available at a nominal cost. The source web site is: http://dmsp.ngdc.noaa.gov/html/services.html

The cost is less than $100 per custom image (depending on what you wish to order). The specifications, as found at the web site are as follows:

OLS Data Delivered	Cost of first orbit (if applicable)	Cost of each additional Orbit (if applicable)
Orbit only - 44 MB each	$15 for the first orbit	$5 each additional orbit
Subset of orbit	$15 for the first orbit	$7 each additional orbit
Geolocated Data	$40 per image (vis and tir files)	or $1.50 per MB
Subset of pre-existing Geolocated Data	$25 minimum (vis and tir files)	or $1 per MB
Data converted to JPG, TIF, GeoTiff or other standard image	$5 additional per image	NA
Print image cost	$5 additional per image on 8.5 X 11 or transparency	NA
MI, T, T2, IES, J4, M		
Orbit Files	$10 for the first orbit	$2 each additional orbit

To pursue this further, we recommend the following be ordered:

Subset of orbit:	$15 for the first orbit
Geolocated Data:	$40 per image (vis file)
Subset of pre-existing Geolocated Data:	$25 minimum (vis file)
Data converted to GeoTiff image:	$5 additional
Estimated Total Cost:	**$85** per geolocated image

To find an example of data that are available, we investigated the web data search facility at: http://spidr.ngdc.noaa.gov/spidr/querydmsp.do

We searched for images taken in early March to April 2005 when evening lights are on and the trees would obscure the least amount of light data. We found that, for a 1-month period, satellite DMSP F16 (one of four DMSP satellites currently operating), had captured 64 images covering the Fort Knox area. Figure 14 shows an example image from which the data pertinent to the Fort Knox study area could be extracted.

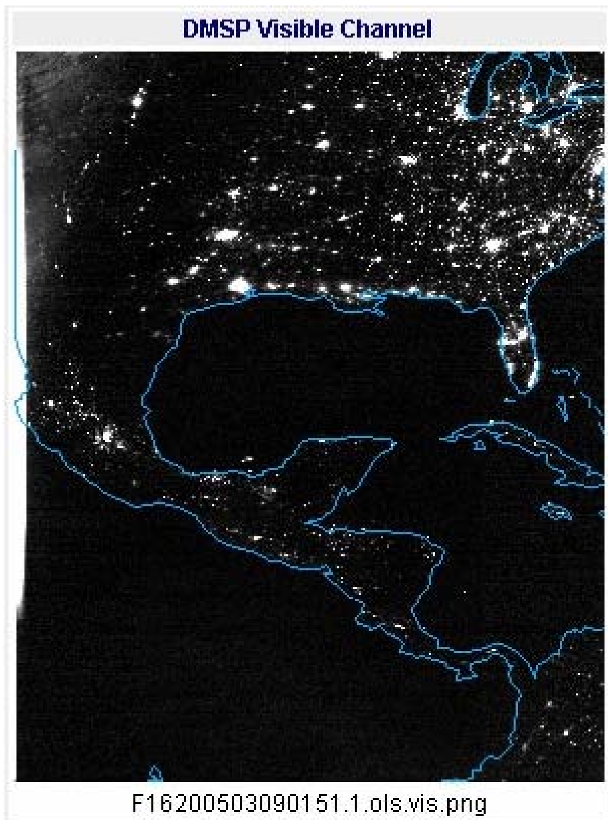

Figure 14. 2005-03-09 23:56:29 F16 night 21.0 -61.100006 F16200503092356.1.

We concluded Phase 1 of this project by noting that current night-light images are available from which up-to-date urban growth distributions can be derived at a nominal cost to the government. Application of the DMSP Night Lights images is a better, more economical, and more contemporary way of estimating the growth of urban areas. It is recommended that this technique be further refined so that the less accurate, more costly, less timely USGS NLCD can be eliminated or at least customized for higher accuracy by the Night Lights data.

6 Phase 2: Land Use Change Modeling and Analysis

The investment in the creation and development of military installations and associated training and testing facilities is substantial. It is important and cost effective to maintain the benefit of the investment in the next decade. Anticipated (or planned) urban patterns surrounding installations can slowly erode the ability to train/test on the installation. The goal of this effort is to convert predicted/planned urban patterns into identification of associated on-installation restrictions. The ability to erode installation-training mission can be evaluated from the perspective of:

- Blast noise and small arms noise
- Generation of dust
- Generation of radio frequency interference to commercial television and radio
- Civilian use of house and vehicle lights during night training exercises

Various techniques have been developed to predict the future of incompatible land uses around military installations. Techniques range from simple questionnaires answered by installation personnel to the development of complex spatially explicit dynamic simulation models. Perhaps the most common approach for predicting the potential for future incompatible land use involves a technique similar to that constituting phase one of this project, i.e., using current and historic digital land use maps to determine how the trend is likely to proceed in the future. By counting the cells deemed to be "urban" in these areas over the time-series of maps, one can create a simple graph of time vs. total amount of urbanized area (Lozar et al. 2005).

These simple trends can be very useful and often sufficient. The extrapolation of past trends can be misleading, however (see Figure 15). Growth might continue to accelerate in situations where there is still plenty of land available for development and where the fringe of a major urbanized area is entering the area of interest. Growth may be moderate if an urbanized center is already in the area and growing along the edge of an installation. It might decelerate if the there is little or no more land available to develop or for unforeseen economic reasons. To help remove the veil of uncertainty, a more careful analysis of the spatial relationships of growing urban centers, available land, natural (e.g., rivers) or man-made barriers (e.g., limited access highways), and zoning can help predict future potentials for incompatible land use situations.

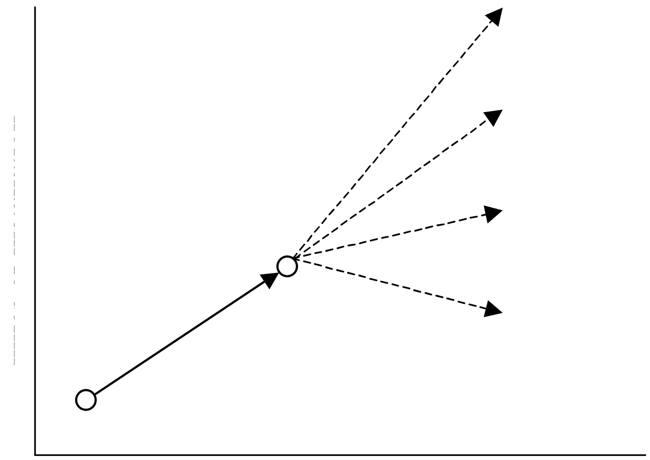

Figure 15. Past trends are not necessarily good at predicting the future.

Many land use change models have been developed and are being used to test alternative land use policies with respect to their impact on future land patterns in and around cities and towns (EPA 2000). The U.S. Army Corps of Engineers is adopting the Land Evolution and Assessment Model (LEAM) to help evaluate how alternative regional policies and land ownership patterns affect future land development. The primary interest is to help minimize future land use conflict resulting from the development of new uses in areas that are and will be impacted by military training and testing activities. All of these good models tend to be expensive to develop and run; consulting firms may charge $500K or more to develop, test, and apply a regional model that generates future land use scenarios in response to proposed regional plans.

The approach used in predicting future development around Fort Knox represents a compromise between expensive, data hungry dynamic simulation models and the simplistic linear progression that relies solely on historic trends. This effort is part of a larger effort that includes the development of a simulation model to project future landscape settlement patterns. The larger effort, LEAM, supports the development of the LEAM land use change (LEAMluc) and LEAM residential attractiveness (LEAMram) models. The use of these models is a somewhat crude but useful predictor of the attractiveness to growth. The suite of models does not allow us to predict where growth will occur, but can help identify where growth is likely to occur.

The work reported here resulted in the development of a map of the attractiveness to urban growth based on the actual settlement patterns in the area. These patterns developed in response to population, employment centers, transportation networks and apparent preferences, but there are several assumptions and caveats that need to be recognized at the outset:

- Other potential attraction considerations could be added to this list, and some on the list could be dropped for any particular location. Note, for example, that drinking water availability is not considered and can be critical from a legal standpoint (e.g., western water rights) or from a geological perspective. Some areas offer more water well opportunities than others.
- Zoning is not considered in this analysis and can be important in the attraction of urban growth.
- This analysis generally assumes no new investments in roads or in the development of new neighborhoods, but can be rerun with such developments provided as inputs. It also does not recognize the effect of development as it affects travel times on roads.
- Travel times are assumed to be optimal for each type of road. Hence, the resulting map provides a snapshot in time of the attraction to new growth, but does not consider the impact of new growth on the overall attraction.
- The analysis identifies attractiveness to new development on a cell-by-cell basis – parcels approximately the size of city lots. While some growth happens this way, much development occurs as part of new neighborhood development sites that can be roughly 800 square meters.
- Parcel size and ownership is not considered. Developers looking to build a new neighborhood are more likely to purchase a single large parcel rather than piece together many smaller contiguous parcels – making urban development less likely.
- Negative attractors are not considered in this analysis. Urban development tends to avoid being co-located with industrial sites.
- The attractiveness to urban growth can be outweighed by attractiveness to other land uses such as parks and industrial areas. This competition is not identified here.
- The attractiveness to cities map must be developed in close consultation with local planners to best capture understandings of the location and attractiveness of local population, employment, and shopping centers.

Approach

Our goal was to generate residential attractiveness maps using readily available national datasets with as little human intervention and operation as possible. The fundamental approach to this process is to use hedonic modeling and establish relative attractiveness values for all locations within the study area. Hedonic modeling is essentially a regression approach that identifies the relative importance of a list of independent variables considered important in setting the price or value of a property (Haas 1922; Wallace 1926; Court 1939). Hedonic modeling is often used in the real estate business to identify the value of a house based on how the individual factors making up the interior of the house and its location contribute to its value (Sirmans et al. 2005). Each aspect of a home and its surroundings imbue some level of pleasure (hedonism), which provides a common currency that allows for the summation of all of the characteristics. Translating this into a willingness and ability to pay yields a monetary value of the property. For this study the value of a house structure is ignored allowing a focus on the fundamental value or attractiveness of the land itself.

The number of characteristics of land parcels to consider can be large, but focusing on a relatively small number allows for efficiencies in evaluation. For this analysis, considerations included in the analysis are: density of surrounding neighborhood, distance to neighborhood forest and water, and driving times to commercial centers, interstates, intersections, state roads, and county roads. However, this list can be easily expanded and contracted for particular applications.

There are two main steps in the analysis process:

1. Acquire nationally available data and resample into a common coordinate system
2. Process the data with GIS scripts

The first is accomplished with the standard GIS technician skill set. The second is an automated processing involving the development and processing of various maps that identify the level of various chosen hedonic attractors. The particular application of the process can involve as many attractors as desired, but the basic process is accomplished with these steps, which are described in more detail below:

1. For each attractor

    a. Develop a map with values representing the attractiveness level
    b. Divide the full range of values into bins (smaller ranges)
    c. Calculate the percentage of developable land developed for each bin
    d. Convert the attractiveness level map into a map of development probability

2. Average the development probability maps
3. Divide the full range of these values into bins
4. Calculate the percentage of developable land developed for each bin
5. Convert the averaged map into a final map of development probability

LEAMluc Procedure

The procedure begins (step1a above) by developing and processing a series of chosen attractor maps. These maps provide a value of the attractor (e.g., driving or travel time to attractors such as businesses, roads, highways, intersections, interstates, water, and forest). The values are factual and must then be converted into levels of attractiveness. That is, how attractive is a driving time of 10 minutes to work compared with 20 minutes, 30 minutes, and so on. There are many approaches to establish such relationships including interviews, which have the advantage of elucidating the opinions through direct query of people in the area. This approach is, of course, costly and time consuming to accomplish properly.

The purpose of the LEAMluc model is to eliminate the need for this extensive interview process. LEAM developers prefer to use evidence of recent building starts or new development identified through the decennial census data developed by the U.S. Census Bureau. This approach has the advantage of capturing preferences within the context of current transportation and communication technologies. That is, it is less important where development has occurred than where it is occurring. While an excellent approach, it does require collection and processing of data that can take more time and effort than is available.

Here, we choose to simply use the land use preferences as expressed in the nationally available 1993 NLCD. The NLCD data and factual attractiveness measure are combined (step 1b) by first dividing the attractiveness ranges into small ranges or bins. Because human responses to the environment are often logarithmic in nature, as described by the Weber - Fechner Law, the log of the attractor may provide a better distribution to divide into equal-size bins. A cross-tabulation of the two maps is made (step 1c), which identifies how many developed and developable areas are associated with each bin. For example, residential areas have NLCD categories 21 and 22. Developable areas can be all areas that are potentially buildable, which exclude water and swampy areas. Dividing the developed by the developable areas counted for each bin yields a percent-developed value. The series of these values across the bins results in a graph (using the values and the midpoint of each range). Finally (step 1d), this graph, linearly interpolated between adjacent points, can be applied to the map of attractor values to yield a probability of development map for the attractor. This process is repeated for each chosen attractor.

At this point, a set of index maps has been generated — one map for each attractor. These must then be combined to create an overall attractor map for development. One approach is to interview local people to acquire trade-off decisions that can be applied to collectively rate a set of attractors using approaches such as Multi-Attribute Utility Theory (Schkade and Payne 1993), the Analytic Hierarchy Process

(Saaty 1996), and the Contingent Valuation Method. This process can be intensive, requiring significant investment in time and money. Another approach is to use a logistic regression analysis to establish an equation with coefficients associated with each attractor that reflect the weight or importance of each attractor (Hosmer and Lemeshow 1989). This often begins with a normalizing of each attractor to a full range of 0-1. Attractors can be multiplied by one another in all combinations to generate further values for which weights can be generated and this process can pick up the importance of attractors in combination.

Unfortunately, this process necessitates the integration of the GIS with a statistics package and requires a technician's skills in both. Our approach does not normalize the attractors, leaving the inherent relative importance of an attractor value in place. For example, an area that has lots of forest may not show that forest is a significant attractor to development and that the probability of finding an area of development at one distance from forest is the same as any other distance. Not normalizing the results leaves attractiveness values that are virtually identical for all locations. All attractiveness values are then simply averaged to generate an overall attractiveness for all locations (step 2). Those attractors that are associated with wider ranges have more effect on the results than those with very small ranges – avoiding the need to statistically generate weights.

The resulting combined attractiveness map must then be evaluated in the same manner as each of the original individual attractiveness maps. That is, the combined map values are divided into sub-ranges (step 3) and then compared with the starting land cover (NLCD) map by cross-tabulating the occurrence of each bin with developed and developable land (step 4). The developed values are divided by the developable (plus developed) totals to generate a graph with the bin mid-points. This graph is applied to the combined attractiveness map to generate the final development probability map. Appendix 2 of this document outlines a more detailed version of the way in which the LEAMluc model processes the data.

Using the Historic Images to Calibrate the LEAMluc Projections

As discussed in the previous sections, the LEAMluc model is a useful tool for the gross prediction of attractiveness of areas for future residential growth. However, as with any model, it does have its shortcomings. LEAMluc does not produce a year-by-year prediction of growth patterns. The actual intervals generated within the model runs are periods of unknown duration, usually assumed to be 1-year periods for each run. In order to look at a particular point in the future (for our purposes the year 2020), we need to objectively calibrate the LEAMluc "Base Scenario" to that particular year.

With the analysis of "urbanized" land from 1970s to 2000 complete, it is possible to graph the results in such a manner that a trend of development over that period can be made. Using this trend, we can then extrapolate growth into the future. The actual intervals generated within the LEAMluc runs are periods of unknown duration, usually assumed to be 1-year periods for each run. The initial scenario was supposed to reflect the urbanized situation after 20 time steps (years) in 2020. We wanted to check this, however, and used the historic trend extrapolation to find where on that growth curve that initial scenario lay, therefore calibrating the actual likely date for the prediction.

The approach we took was a five step process:

1. From the Historic urbanization data, extract the percent of development per unit study area for each decade.
2. Graph the Historic percent of development for each decade.
3. From the LEAMluc "Base Scenario," extract percent of development per unit study area.
4. Determine where on the Historic percent of development graph the Historic percent of development lies, thus reading off the projected date of the "Base Scenario."
5. Determine the percentage value for developed land in the region for the year 2020.

Results

1. *From the Historic urbanization data, extract the percent of development per unit study area for each decade given known data.*

This was done in section 2.

2. *Graph the Historic percent of development for each decade.*

As previously reported in section 2, we determined that the region has been adding roughly 2% developed land every decade.

3. *From the LEAMluc "Base Scenario" extract percent of development per unit study area.*

# Non Urbanized Cells	# Urbanized Cells	Total number of Cells	% Urbanized	Calculated Year of Projection
8645438	726312	9371750	7.75%	2007

4. *Determining where on the Historic percent of development graph the Historic percent of development lies, thus reading off the projected date of the "Base Scenario."*

From the calculations in the preceding table, it can be seen that the projected year for the Base Scenario is 2007. There is a likely error of 2 years based on backward engineering as described in step 2. Since we have previously believed that the Base Scenario represented a 2020 projection, it is unlikely that it does. Based on the assumption that the projections began in the year 2002, this means that each LEAMluc step or period actually represents about one-third of a year increment rather than 1-year periods. The historic data shows growth to be roughly a straight-line trend, rather than a logarithmic or geometric curve. Since the straight-line trend is simple and corresponds to common sense, the equation developed in this report based on this simple assumption and historic data is not likely to be in error by more than a few years. Clearly, therefore, the Base Scenario cannot represent a 2020 situation; in fact, at the outside range it might be 2009 or 2010.

5. *Determining the percentage value for developed land in the region for the year 2020.*

Since we now know that the Base Scenario does not reflect the built out statistics for the year 2020, what percentage will? To define this parameter, we need only resolve our equation for the unknown, percent developed, since we know the year we wish to inquire about is 2020.

%Urbanized

= ((Date of Projection-1972) * 0.18) + 1.37

= ((2020-1972) * 0.18) + 1.37

= 10.01

Summary of Validation Efforts

The LEAMluc projected "Base Scenario" was compared to the trend that was developed from the historic NALC and NLCD data. That trend shows a roughly straight-line growth curve for the study region. To represent a projection 15 years into the future, the amount of land within the region that should be converted to an urban land use was expected to be about 10% in 2020. Figure 16 shows the development predicted before the model was recalibrated. NLCD data for 2001 representing urban areas is shown in red (6.5% of land use). Predicted development from the Base Scenario is shown in blue (7.7%).

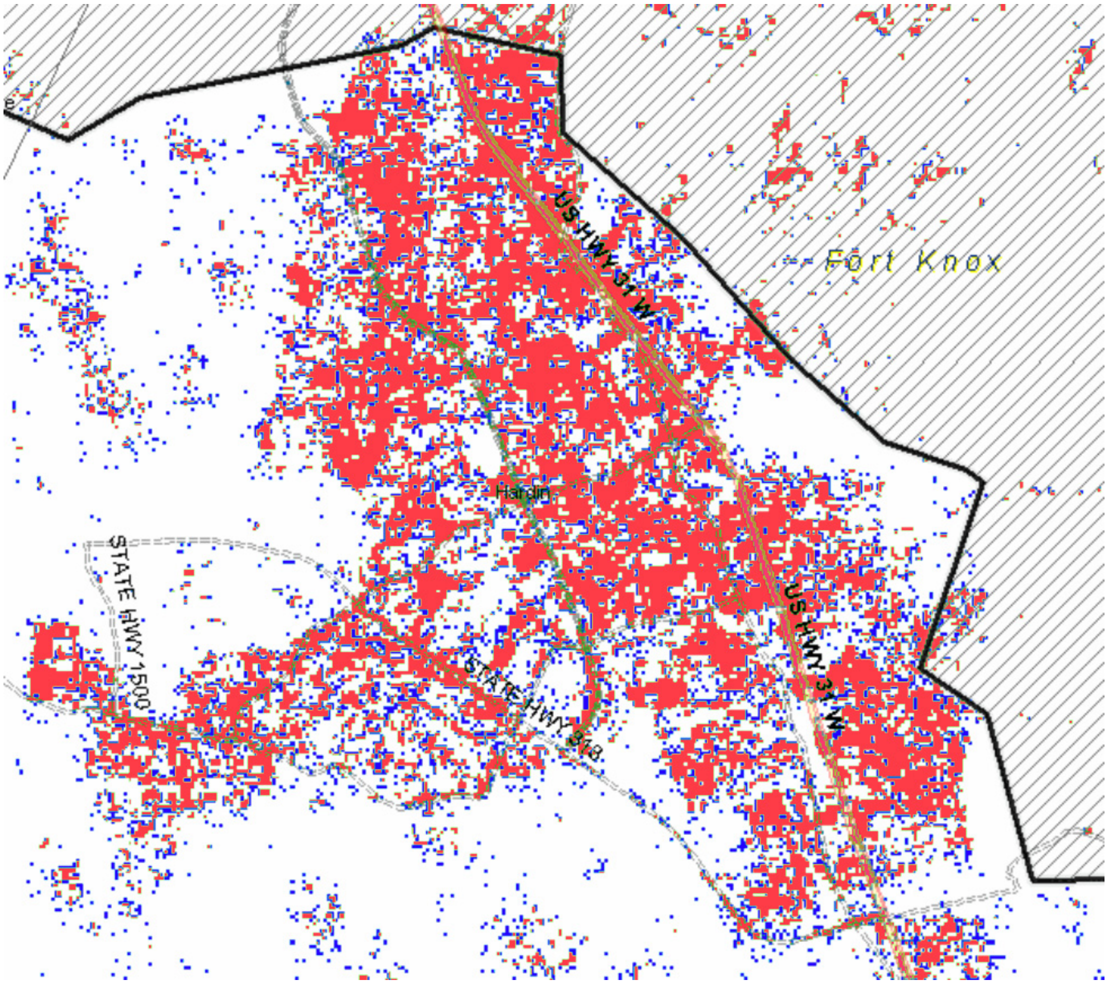

Figure 16. Development in 2001 vs. predicted development in 2020 before calibration of LEAMluc model.

Using the simple equation derived in Phase 1, we were able to determine that the initial base scenario represented regional growth of about 7.7% at the end of the simulation. Projected out to the future, this showed that the scenario predicted out only as far as the year 2007. Simplified, the blue areas should have been about 2.3% more in Figure 16 if we were really looking at predicted growth for the year 2020.

We then went back and adjusted the algorithm used by LEAMluc and recalibrated it accordingly, to bring subsequent model runs more in line with that 10% target development figure. In this way, all future scenario runs would reflect the same growth curve the region has experienced in the past.

Modeled Scenarios

Base Scenario

With the model returning reasonable results, we ran three different scenarios when looking at attractiveness to urban growth. The first was the base scenario we have been discussing, which predicts where future growth is likely to occur given no additional information with which to parameterize the model. This scenario forecasts residential attractiveness without considering future changes to roads, highways, or other infrastructure. Additionally, the only no-growth areas considered were those known to exist in the study area today (swamps, water, parks, Fort Knox itself, etc.)

Figure 17 shows the residential attractiveness map for the base scenario. (Note: these residential attractiveness maps are not predictions of where growth will occur, simply a visual indication of an area's relative attractiveness to other areas.)

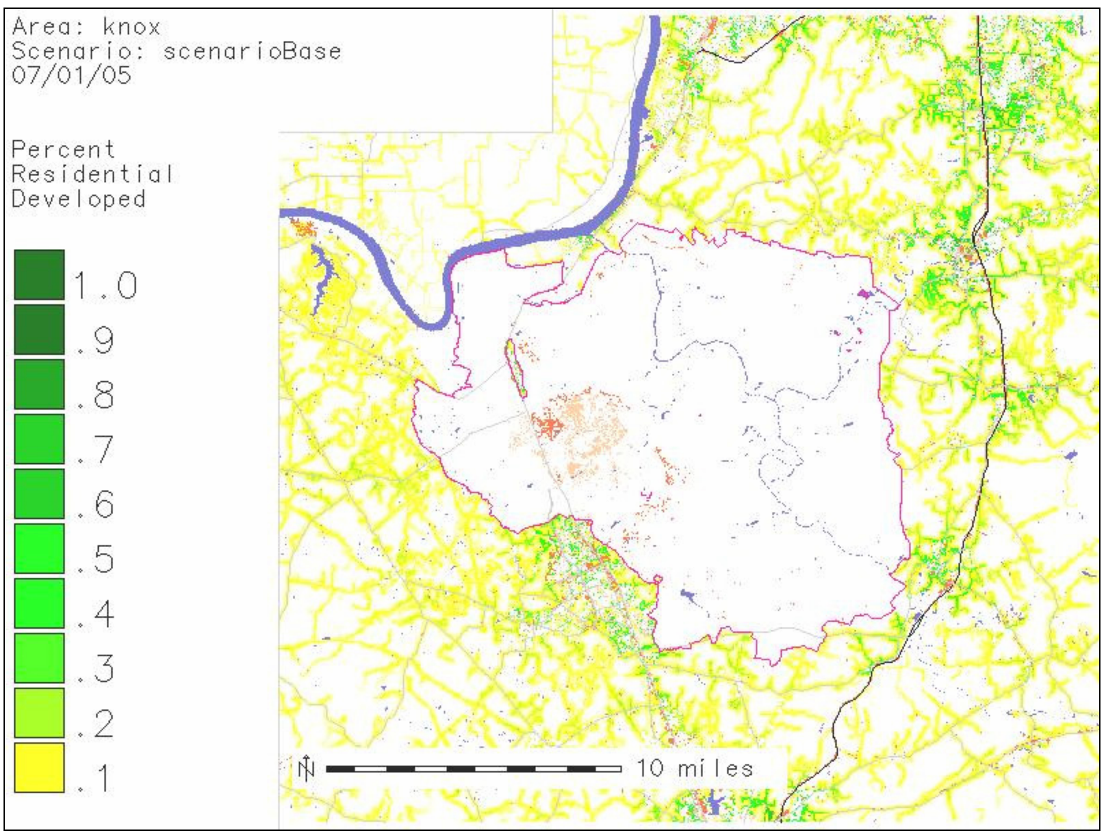

Figure 17. Residential attractiveness map for Base Scenario.

New Roads Scenario

The second scenario takes into account new roads planned within the next 6 years. GIS data on new road construction was obtained from the Kentucky Transportation Cabinet and outlines additions and improvements to routes in the study area over the next 6 years. These changes to the road system were incorporated into the road map GIS layer required by LEAMluc to run the scenario. There is one caveat regarding this scenario, however: The information provided by the Transportation Cabinet was derived from Kentucky's 6-year Highway Plan, and although this data is the best available at the time the simulation was executed, it may be subject to change, depending on financial resources and other factors in the years to come. These residential attractiveness maps are useful in determining where growth may occur in the future, but they are limited in providing a visual sense of what that growth might look like in 15 or 20 years.

Figure 18 shows road improvements and new road construction projects most likely to affect Fort Knox. Figure 19 shows the updated residential attractiveness map that considers these future changes to the infrastructure in the region.

A Quicktime movie depicting what development might look like in 2020 can be viewed by clicking this link: Base_Scenario movie.ppt . This animated presentation allows the viewer a better understanding of the region's growth through time. Given the nature of the model, and the fact that some degree of randomness is programmed into it, the output maps used to generate this animation will differ slightly every time the model is re-run. This means that the general pattern of future development will be similar in all runs, given the same input parameters, but the details will vary slightly.

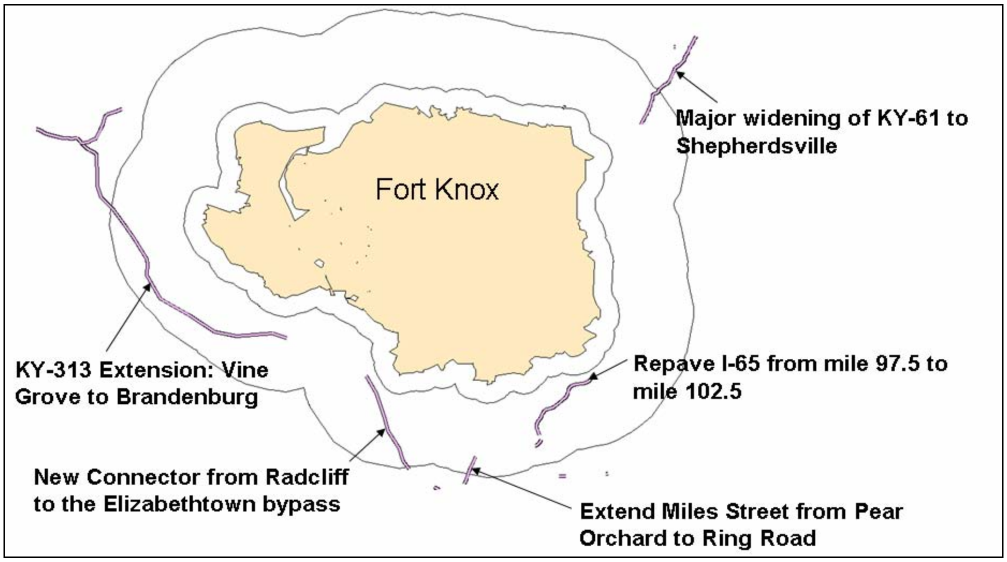

Figure 18. New roads and road improvements slated for construction in KY 6-year highway plan.

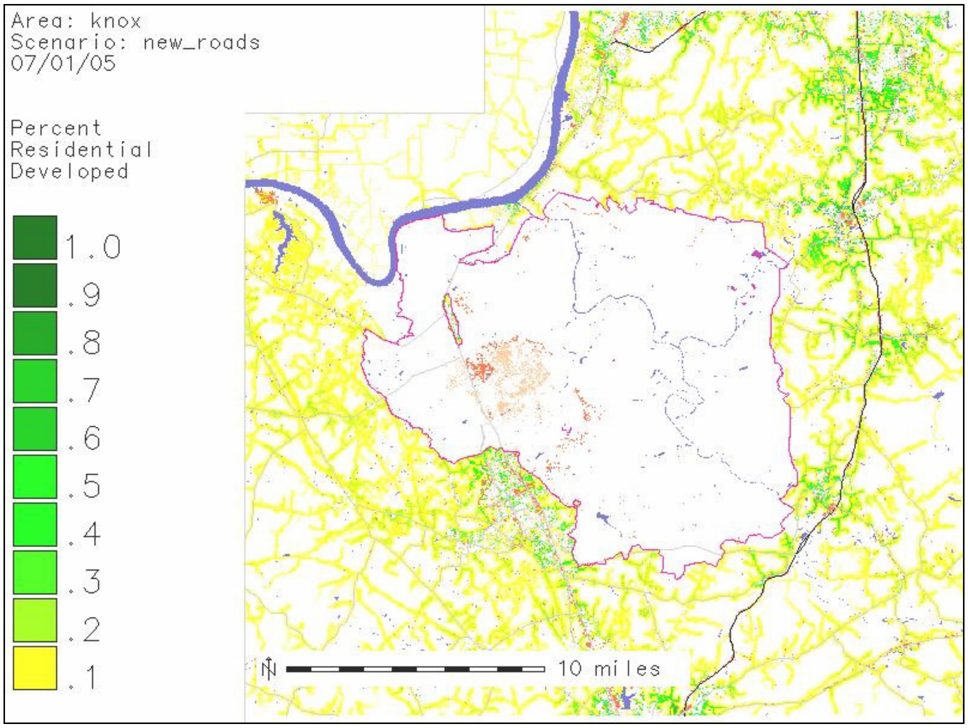

Figure 19. Residential attractiveness map for New_roads Scenario

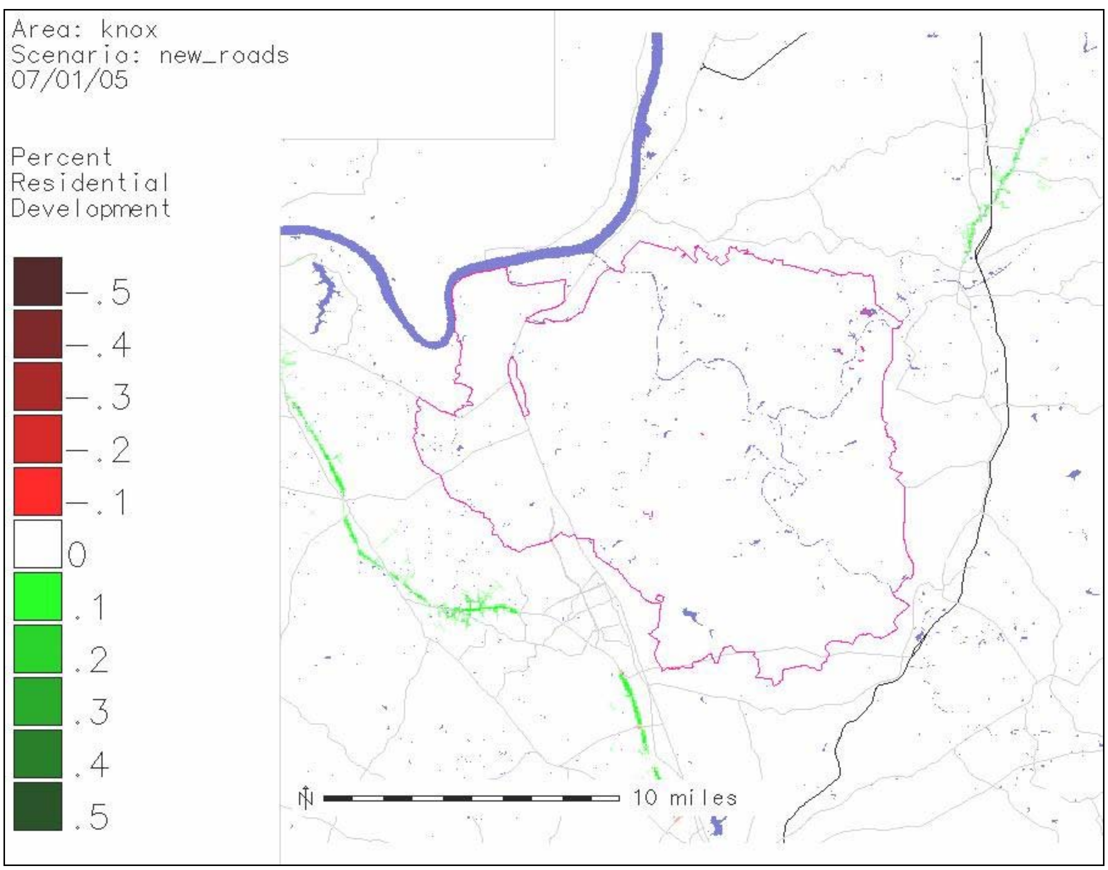

Figure 20. Map depicting differences between Base Scenario and New Roads Scenario.

Figure 20 depicts the differences in the residential attractiveness map between the Base Scenario, and the one simulating changes given the road improvement and additions outlined in the KY 6 Year Highway Plan. Note the increase in residential attractiveness as indicated by the green areas to the south and west of the installation boundary. This is due to the addition of a new connector road from KY-313 at Radcliff west of us-31w to the Elizabethtown bypass (Ring Road). KY-313 is also slated for improvement between Radcliff and Brandenburg, making travel times in areas west of Fort Knox shorter and more attractive to residential growth. A movie displaying the New Roads Scenario growth pattern can be seen here: New Roads scenario movie.ppt.

Conservation Agreement Scenario

The third scenario examines what might happen if Fort Knox and the Army were to enter into a series of conservation agreements with land holders owning property adjacent to the installation boundary. We examined both the output from the Base Scenario and the historic land use trend data to make our best guess as to where agreements of this nature would best benefit Fort Knox in terms of conserving training areas still useable within the installation boundary.

The Southeastern Ecological Framework (SEF) (Durbrow et al. 2001) served as a good indicator of where we should concentrate our search for candidate land for this scenario. The reason we identified and used the SEF in selecting the area we did for no-growth, was in the nature of the Framework's effort. The SFE project is a GIS analysis to identify ecologically significant areas and the connectivity between those areas in the southeastern region of the United States. The states included in the project are Florida, Georgia, Alabama, Mississippi, South Carolina, North Carolina, Tennessee, and Kentucky. The project's goals were:

- To identify primary ecological areas that are protected by some type of conservation or ecosystem management program
- To identify a green infrastructure network that connects these primary ecological areas
- To identify the important ecological characteristics of the ecological areas and connecting green infrastructure
- To develop an understanding of the spatial scale issues involved in analyzing the ecological connectivity at local, state, and regional scales
- To develop a protocol for dissemination of the information.

In general, the Framework identifies most military installations as regional hub areas (largely because they contain vast tracts of remnant undeveloped lands). These hubs are connected to other hubs through corridors. The corridors are natural lands that typically correspond to riparian areas in the Southeastern United States. Most of Fort Knox is designated as one such hub. In fact, Fort Knox is nearly the largest single parcel of SEF land in the region (Figure 21). We took a closer look at the character of the SEF lands within the 1- and 5-mile buffers to see what those areas might mean for Fort Knox (Figure 22).

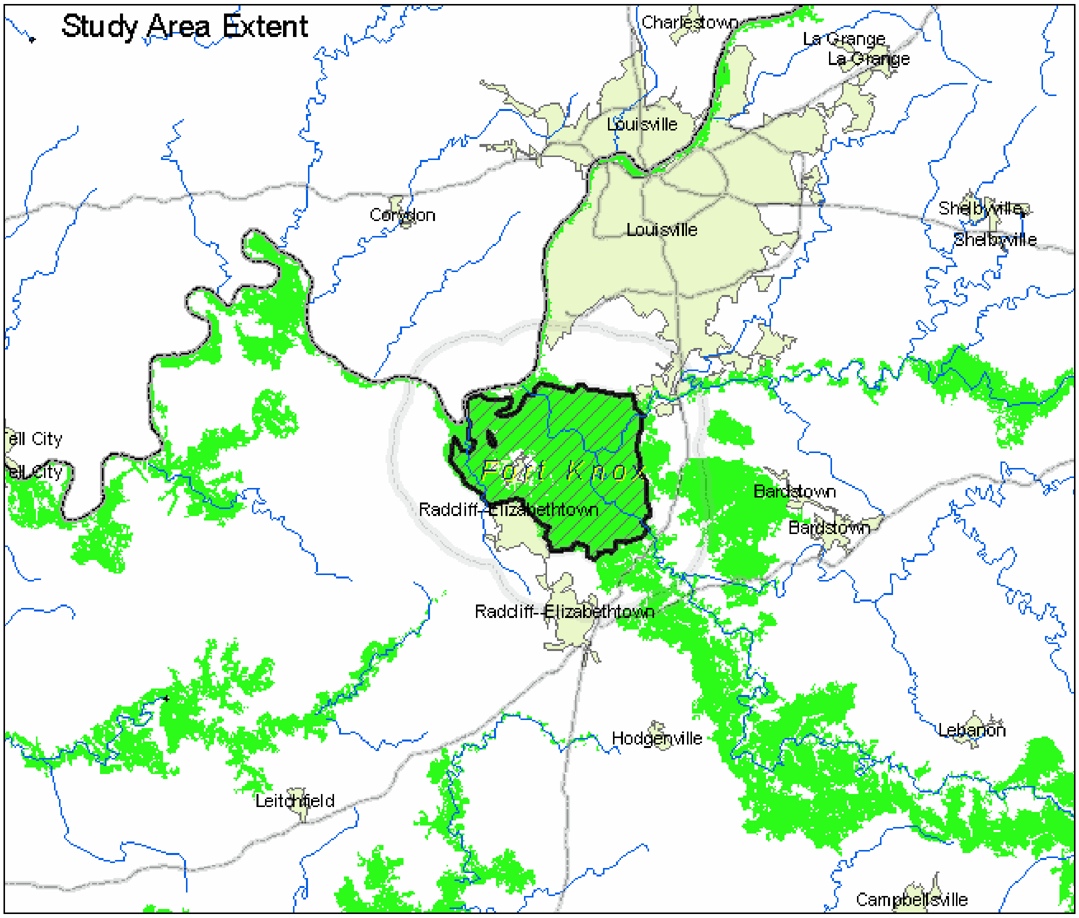

Figure 21. The SEF (green) and the 5-mile buffer within the Fort Knox Study Area.

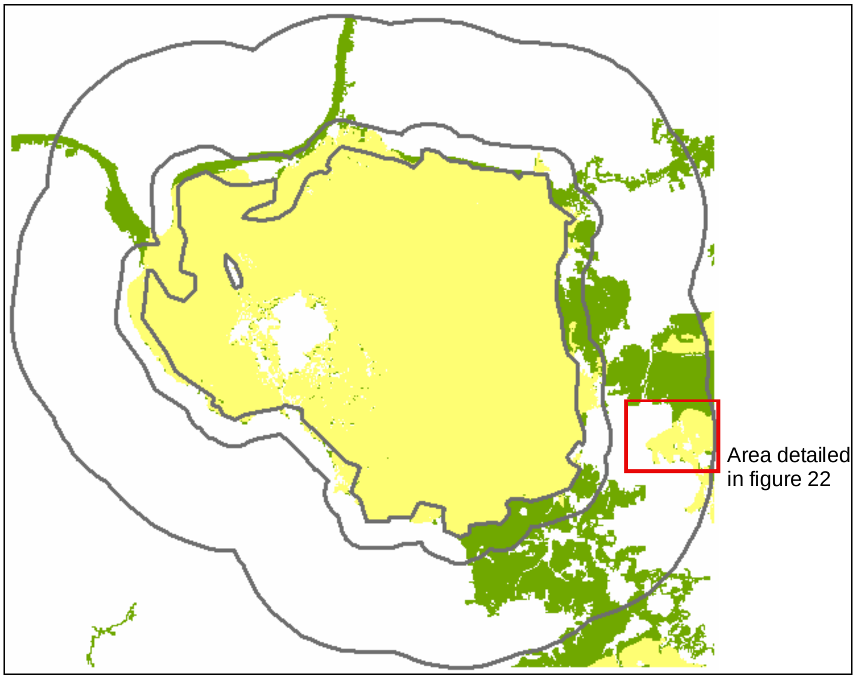

Figure 22. Southeast Ecological Framework (SEF) in relation to the Fort Knox 1- and 5-mile buffers. Yellow areas are hub districts; green are SEF corridors.

As outlined in Table 8:

- Within 1 mile of Fort Knox, nearly half the land is of sufficient natural quality to be designated part of the SEF. About a quarter of the land within 5 miles has also been so designated.
- About a quarter of the land within 1 mile is identified as "hub" land.
- Within the 5-mile buffer, much less land is identified as "hub," but there is still some existing there.

Table 8. Distribution of the SEF near Fort Knox.

Concern	% SEF in 1 mile	% SEF in 5 mile
sef	49.7	23.5
sef_hubs	26.8	7.0

Although much less land is identified as "hub" within the 5-mile buffer, a clearly identified parcel warrants this distinction on the eastern edge of the 5-mile buffer (Figure 23). It begins 1 kilometer southeast of Camp Crescendo, at the ridgeline, and continues roughly 3 kilometers further to the southeast in the hilly area. The hilly area between Camp Crescendo and the ridgeline is not included. SEF corridors connect this hub area to Fort Knox on its west-central boundary. A large portion of this corridor is contained within the 1-mile buffer near Mumford Cemetery, extending to Indian Knob (Figure 24). This portion of the SEF borders Range Area D.

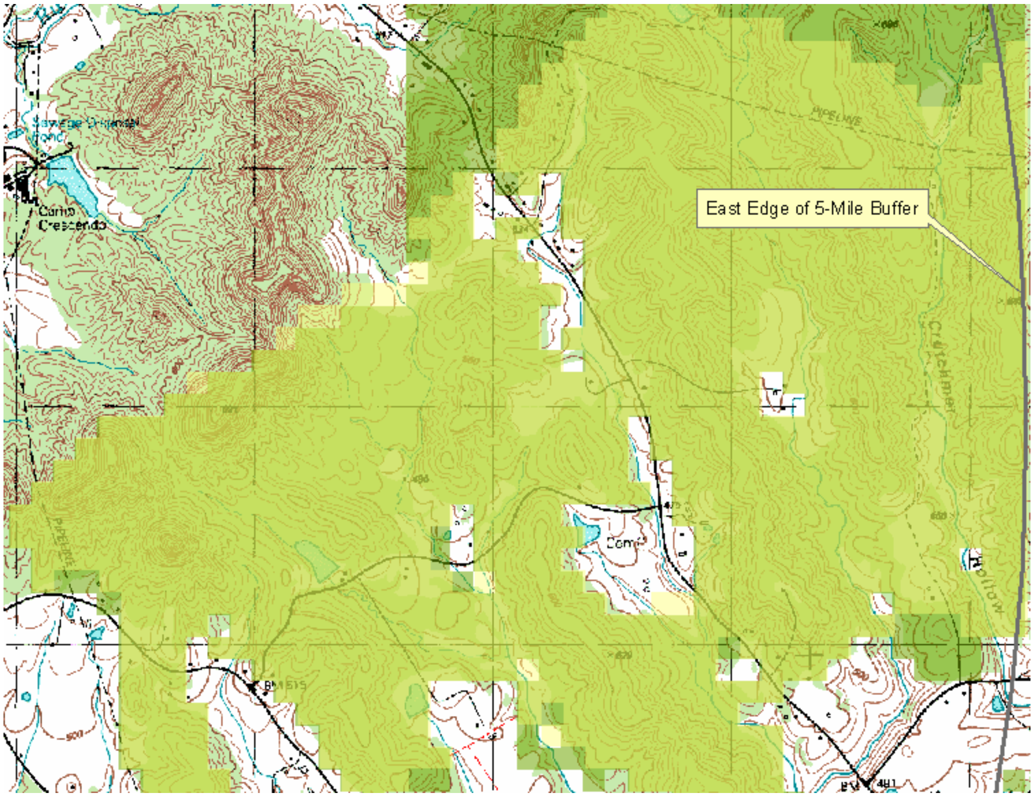

Figure 23. The large SEF hub (light green shading) at the east edge of the 5-mile buffer with topography from 1:24,000 USGS Quads.

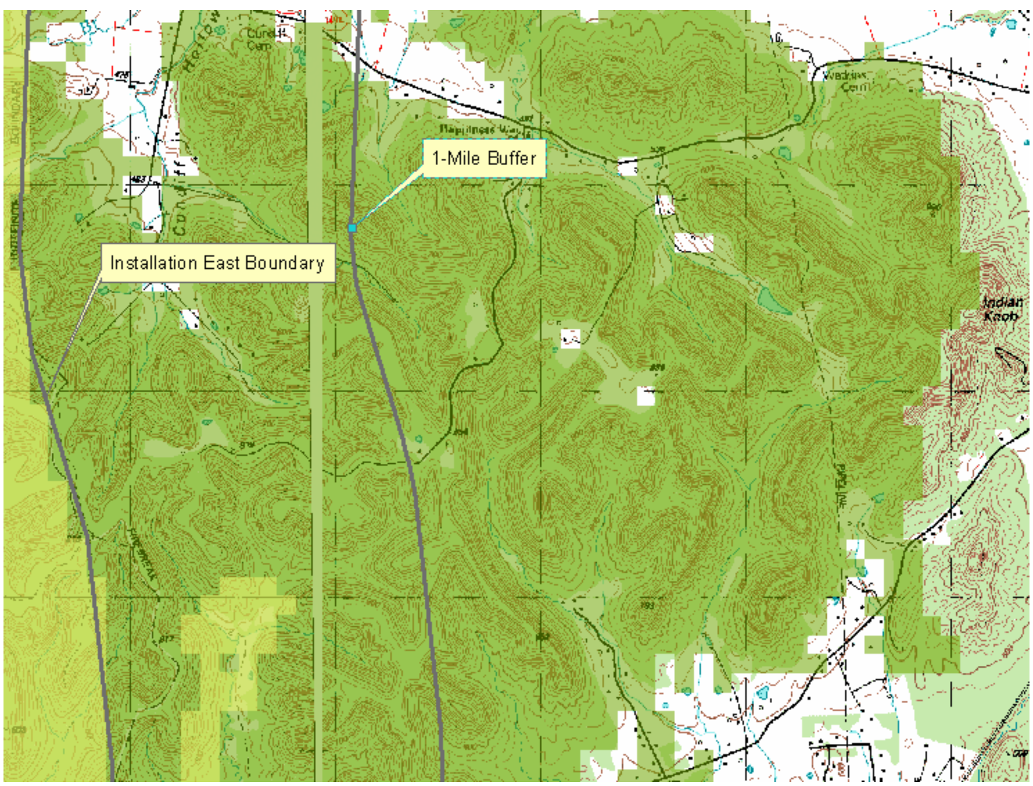

Figure 24. SEF (shaded green) on the east side of the installation to Indian Knob.

A section of the Framework also occurs at the northeast corner of the installation along Salt Creek and Froman Lake (Figure 25). It appears that much of this area has already seen urbanization, making it unattractive for our conservation agreement scenario. On the other had, this is also the area that will be most impacted by the new range complex in this region. Currently, this portion of the SEF borders Range Areas B and D.

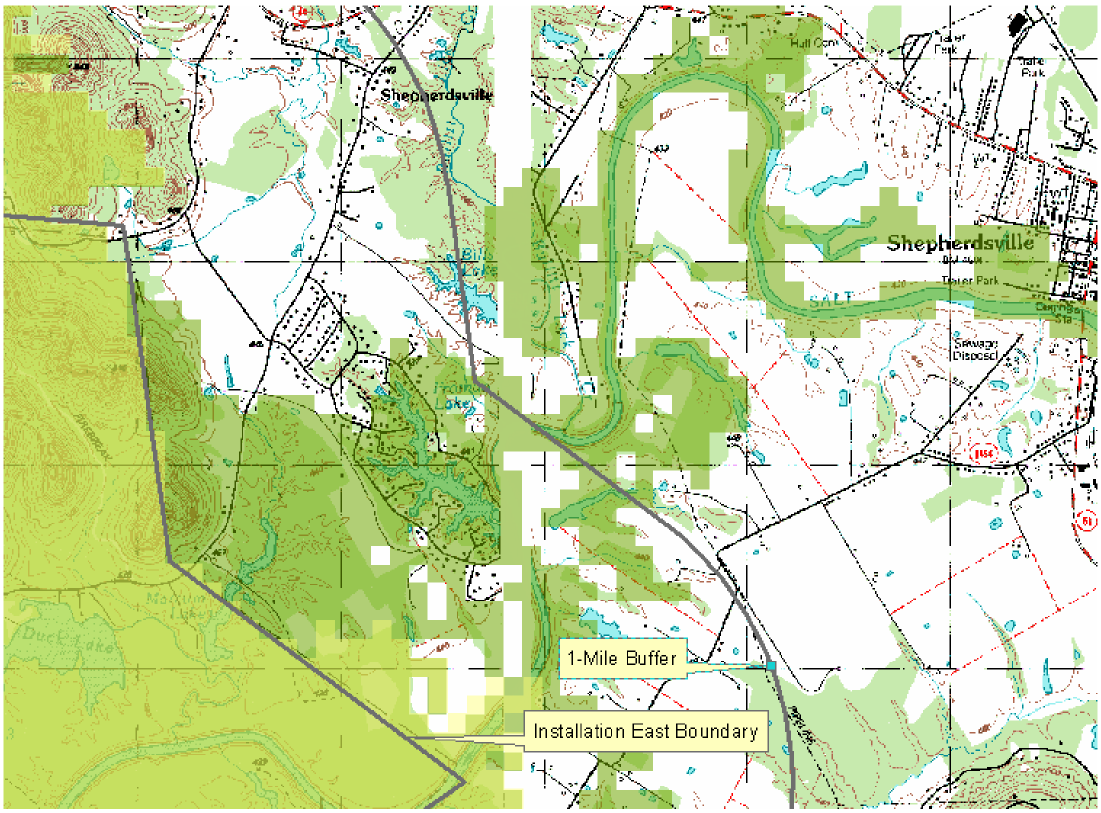

Figure 25. SEF (green rectangle shading) in the area near Froman Lake.

The region at the Southeast Corner of Fort Knox is bounded by a large patch of the SEF near Colesburg (Figure 26). This is an extensive area adjacent to the installation and within both the 1- and 5-mile buffers. This region is near the 40-MM Grenade impact area on the installation.

These areas all made good candidates for conservation easements in our scenario because of their recognized importance by the EPA. Knowing where these areas were, we then had to determine which of those lands might be set aside to yield the maximum benefit in preserving the training opportunities on Fort Knox. We then turned to the annoyance tolerance maps (explained in the Preliminary Work in Establishing Annoyance Tolerance Maps section of this report) to help determine where the new areas of no-growth should be located for the purposes of this third scenario.

We identified the area outlined in Figure 27 as potential lands on which to focus the energy and resources necessary to establish conservation agreements between land holders and Fort Knox. This tract of land extends east from Shepherdsville Road to Cartwright Estates and south from the boundary of Fort Knox to Battle Training Road (State Highway 434) as seen in Figure 28.

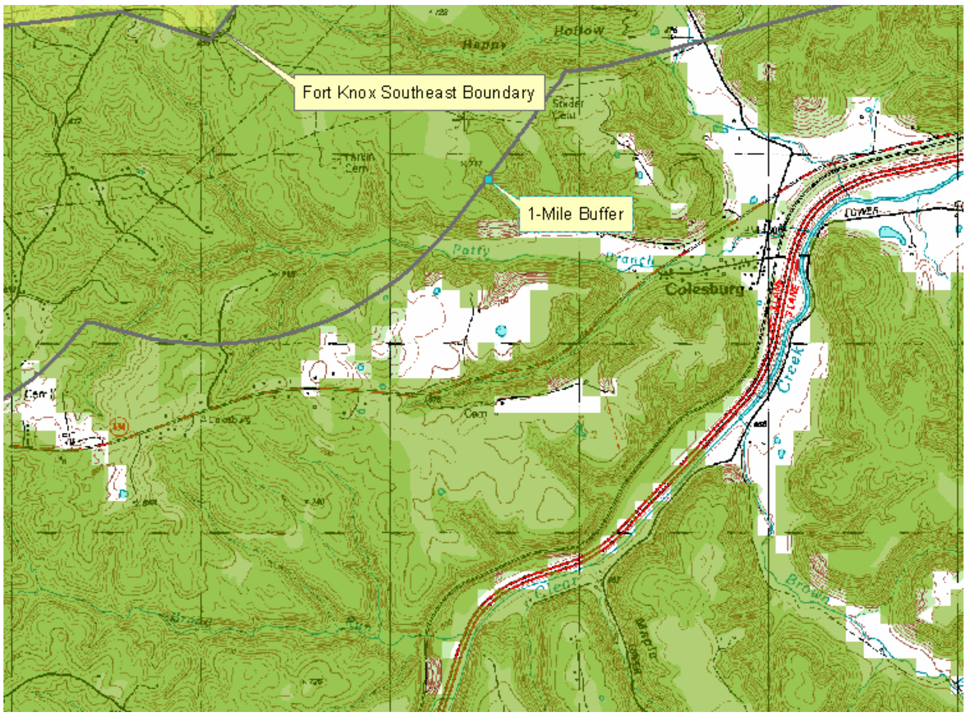

Figure 26. Region of the SEF (darkened green rectangles) at the installation's southeast corner near Colesburg.

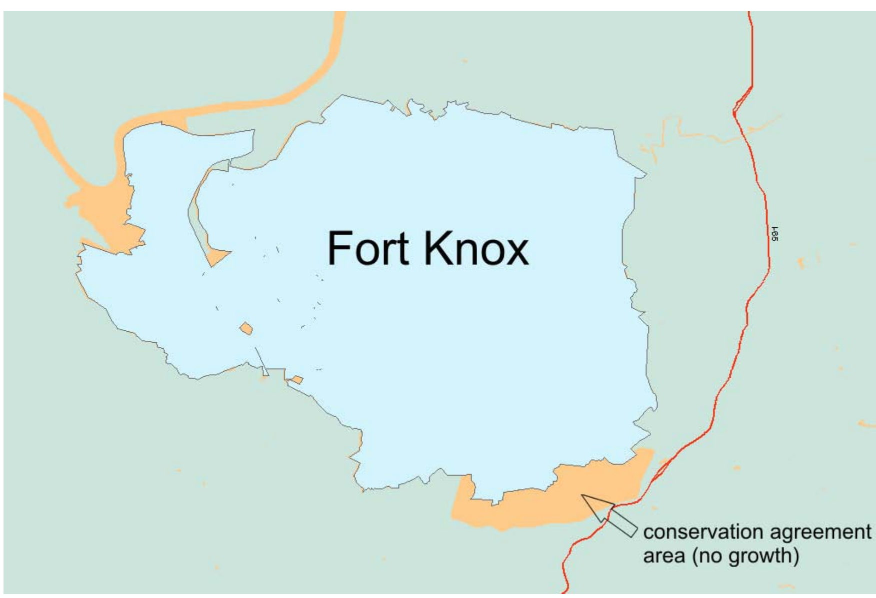

Figure 27. No-growth area simulating conservation agreements established between land holders and Fort Knox.

Of course, this block of properties represents a best-case scenario. There is no indication, at this time, that such a large tract of land could be set aside under any conservation agreements, but this is where we felt the best options for possible procurement of lands lay. The map in Figure 28 shows the residential attractiveness map resulting from this scenario. The effect of this can also be seen in the Training Annoyance Tolerance contour for this scenario (Figure 34).

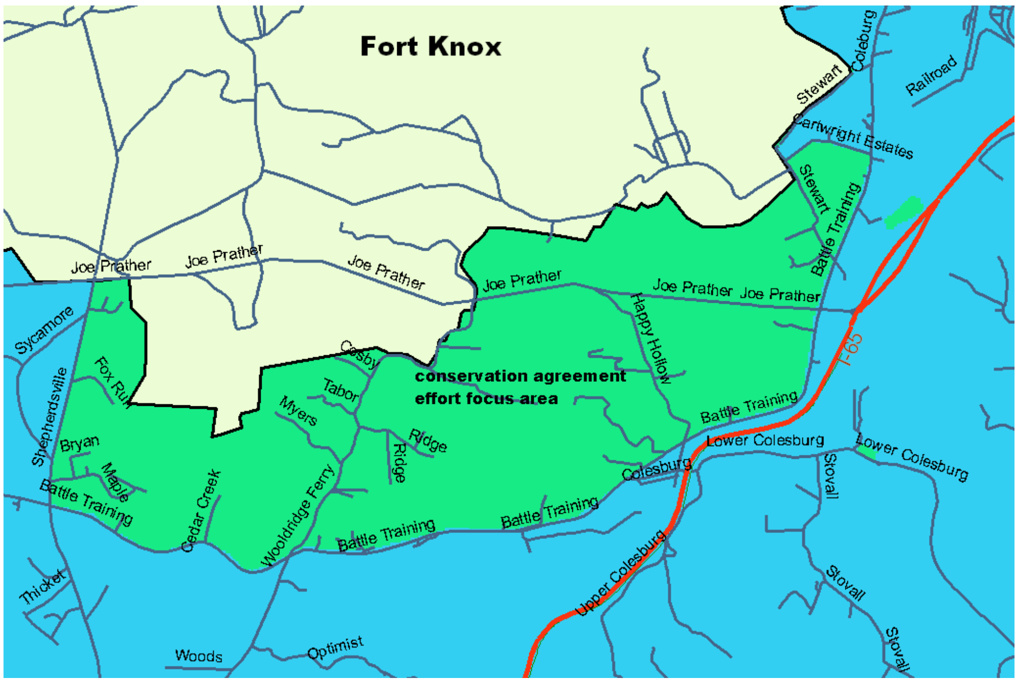

Figure 28. Detailed area of where conservation agreement efforts should be focused.

Figure 29 shows the residential attractiveness map for the Conservation Agreement Scenario. Note how the area to the south of Fort Knox is now unattractive for urbanization due to the simulated agreements between Fort Knox and nearby landholders. A movie displaying the Conservation Agreement Scenario's growth pattern can be seen here: Conservation Agreement scenario movie.ppt.

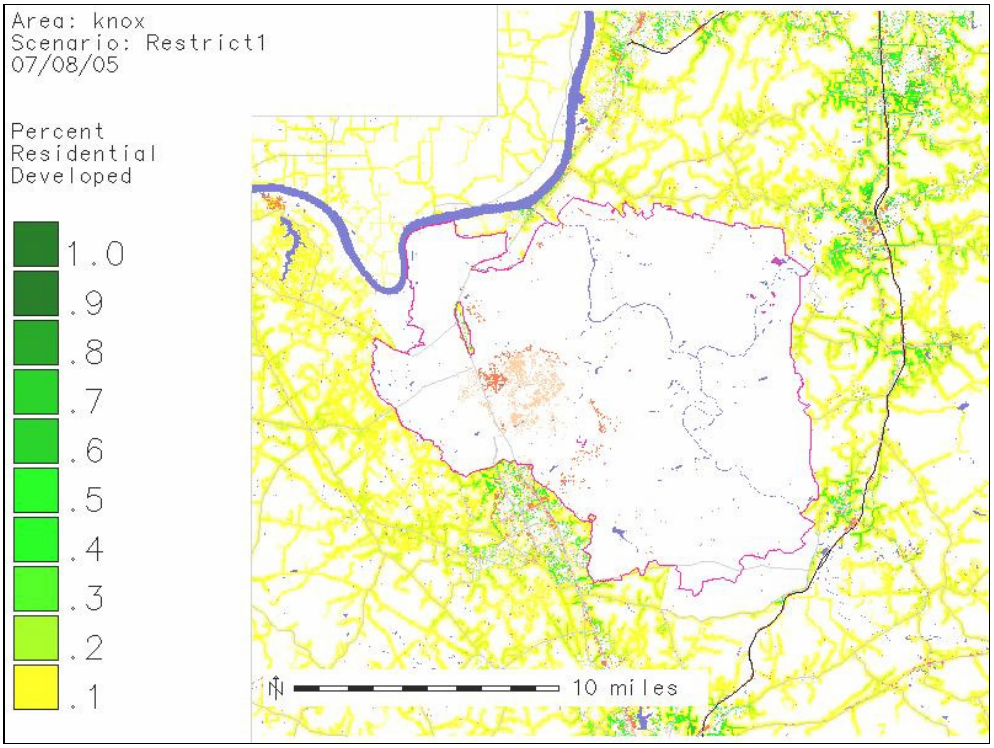

Figure 29. Residential attractiveness map for Restrict_1 Scenario.

Another area that should be investigated for opportunities in cooperative agreements between Fort Knox and local land holders is the area to the west of the installation. This part of the Ohio River Valley is currently in agricultural production. Today, urbanization is minimal, but simulations using LEAMluc do forecast residential development to grow in these area. This scenario was not modeled because designating this farm land as a no-growth area would have little effect on the annoyance tolerance contour for Fort Knox, but felt it was worth investigating to see what kind of agreements could be entered into between farmers and the Army. NRCS or some other agricultural agency or organization may have ideas on how this could be accomplished.

Analysis of the Three Scenarios

An analysis of each of the three scenarios was performed to see how future growth might affect Fort Knox. We focused on the areas as characterized by our buffers. While it is not possible to predict exactly which locations will become urbanized, it is feasible to predict which locations are the most attractive to urbanization. Further, if we know how much land is expected to be urbanized by 2020 (~10.1% as predicted using the historical trend analysis), then we can expect that the LEAMluc model will forecast a similar degree of growth. The question then becomes, "How attractive is the land near Knox to development? Is it more or less attractive for development than the regional average of 10%?" Figure 30 shows the final Base Scenario distribution (blue) for the entire study region.

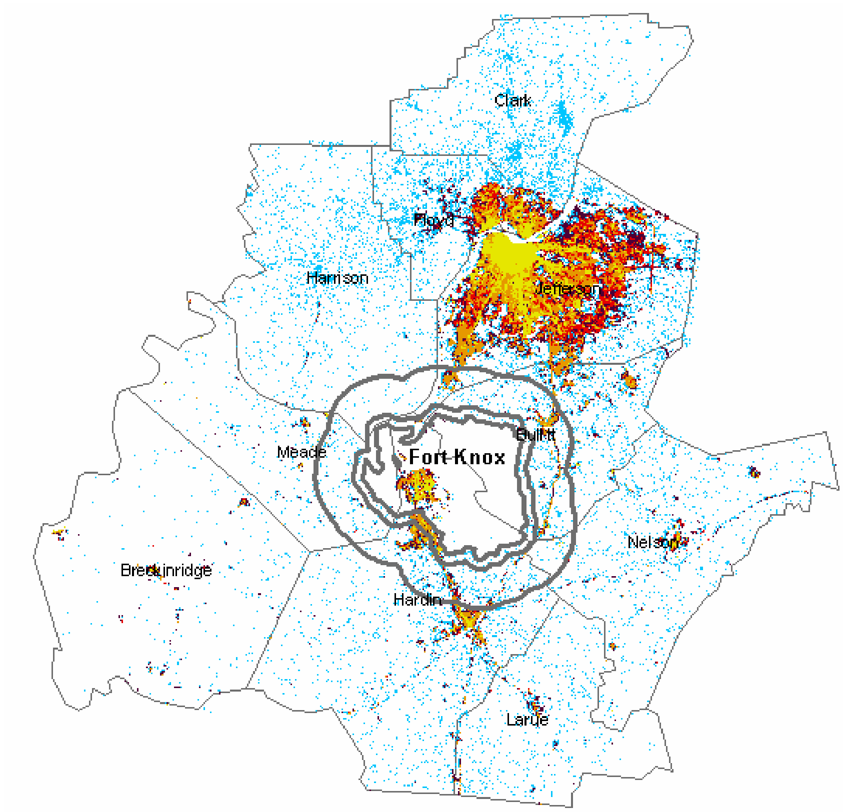

Figure 30. Study Area Base Scenario Urbanization (blue) with historical urbanization 1972-2001 as yellow-red-black respectively.

Our first and most basic question was, "Does this represent a year 2020 projection?" Table 9 gives the statistics for this map.

Table 9. Analysis of study area.

Concern	# Urban Cells	# Not Urban	Total # Cells	% Urban in Study Region
Leam 2020 Urb Study Area	1,332,139	9,928,060	11,260,199	11.8

The result is that the urbanized area within the region is greater than would be expected in the year 2020. It is easy, however, to calculate the year the map does represent from the equation derived in the trend analysis:

Date of Projection =

= (%Urbanized-1.37)/ 0.18 +1972

= 2029.92

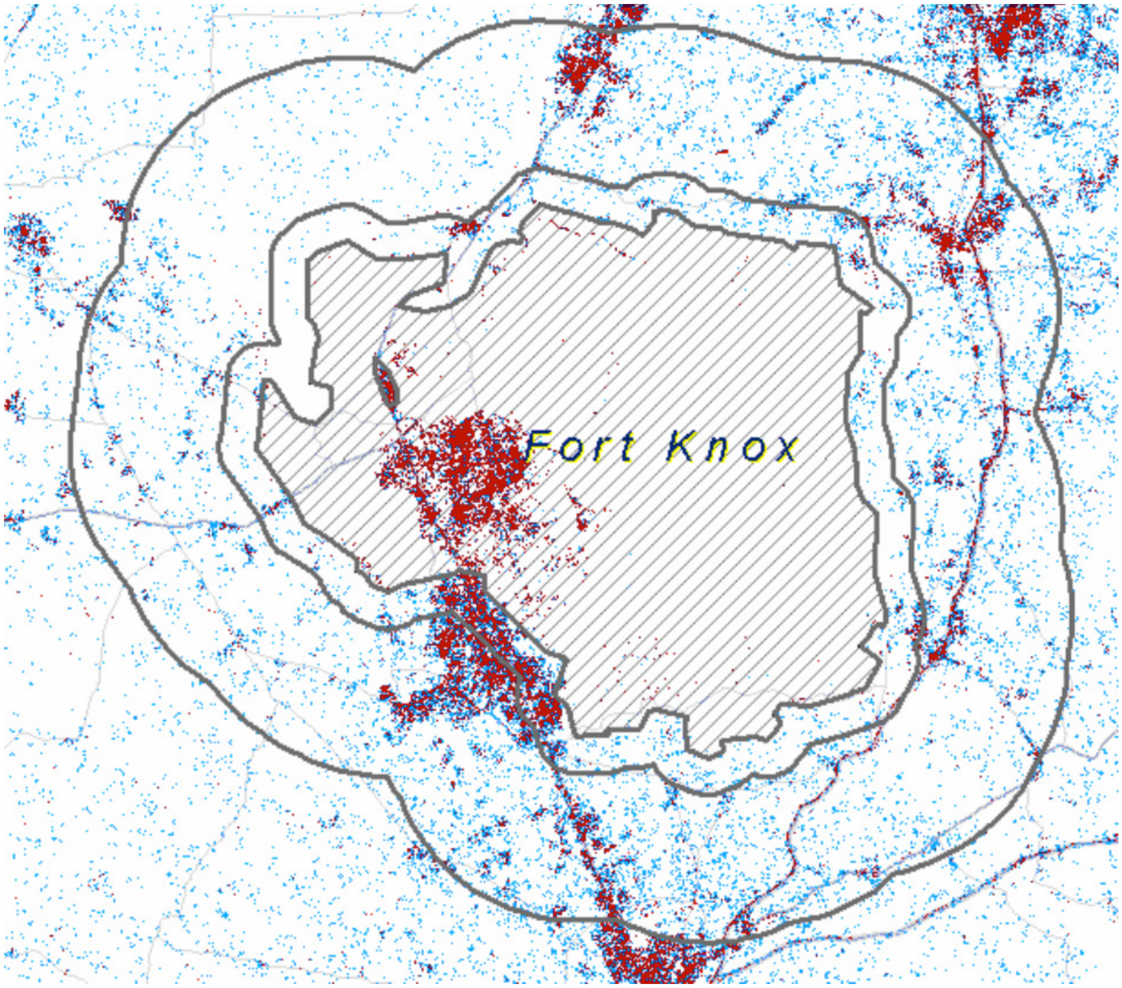

Figure 31. Region immediately around Fort Knox with the 2001 existing urban areas (red) with the Projected 2030 likely developed areas (blue).

The map likely represents urbanization in the year 2030 rather than 2020. Although this is off by a decade, this is not a problem for our purposes because the issues we are investigating will only be more pronounced given another decade of change. Further, all the other scenarios were run with the same basic assumptions and parameters. They are still comparable, even though each will show a greater density of urbanized land (11.8%).

Figure 31 shows the map distribution of urbanized land for the base scenario for the year 2030 in blue while the red area represent the beginning urban land uses from the 2001 USGS NLCD data. Table 10 represents the analysis of the three scenarios in the buffers around Fort Knox.

Table 10. Statistics for various 2030 scenarios near Knox

Concern	Urban Pixels of Concern in 0-1 mile buffer	1-5 mile buffer	0-5 mile buffer	Not urban	Total Pixels in 1 mile buffer	5 mile buffer	% Urban in 1 mile	% Urban in 5 mile
Leam 2030 Base Urb Study Area	25,091	102,688	127,779	903,307	186,829	1,031,086	13.4	12.4
Leam 2030 Restricted Urb Study Area	23,670	102,352	126,022	905,064	186,829	1,031,086	12.7	12.2
Leam 2030 New Hiway Urb Study Area	23,636	102,407	126,043	905,043	186,829	1,031,086	12.7	12.2

From these figures, we can determine the following:

- In all cases, urban growth near Fort Knox will be greater than the regional average of 11.8%.
- In all cases, urban growth will be greater in those lands closer to Fort Knox (the 1-mile buffer) than those further away (the 5-mile buffer).
- For the 1-mile buffer:
  - The Base Scenario resulted in a significantly higher growth rate than the others (1.6%).
  - Both the Restricted and New Highway Scenarios show greater than average growth rate (by nearly 1%). Over time this can be expected to become significant.
  - There is no significant difference between the Restricted and New Highway Scenarios. This is likely due to the random probability inherent in the LEAMluc model. Running each scenario over a number of times and averaging the results would probalby yield more normalized differences.
- For the 5-mile buffer:
  - Although the growth rate is greater than the average for the region in all three scenarios, this rate only shows a maximum of 0.6 % difference in the base scenario.
  - Both the Restricted and New Highway Scenarios show a growth rate much closer to the regional average.
  - There is no difference between the Restricted and New Highway Scenarios.

As a result of this analysis, we see that the pattern observed in the historic trend analysis will continue in the future, and land directly beyond the installation boundary is at the greatest risk for urbanization.

7 Preliminary Work in Establishing Annoyance Tolerance Maps

The long-term viability of proposed new training and testing ranges must be made with respect to the impacts of future as well as current neighbors. Although there may be no residential neighborhoods in areas impacted by a proposed firing range currently, the development of such neighborhoods in the future may significantly decrease the long-term cost-effectiveness of the construction of the range. Defacto ownership can be problematic to establish and may be insufficient to prevent future developments. Instead, DoD can use various authorities to purchase land outright or to purchase property development rights that will prevent future developments (see Appendix 4), thereby ensuring the long-term viability of a new range.

Unfortunately, the long-term viability and sustainability of a military installation and its associated training and testing areas is based not only on its ability to sustain a current mission, but to accommodate future unknown missions. Recently, the DoD completed the latest round of Base Realignment and Closure (BRAC) analysis that will result in the re-stationing of many troops, soldiers, and airmen. Installations are analyzed with respect to their long-term ability to accommodate missions. Those installations facing significant nearby urban growth now and in the future must be viewed as less able to sustain military training and testing because of 1) the probability of increased complaints from residential areas, and 2) the inability to expand the training and testing ranges into adjoining areas. As a result of each BRAC exercise, the training and testing mission at an installation can significantly change both in the level of training throughput and the type of training provided. Therefore, planning for the long-term viability of military installations and the economic base they provide to their supporting communities must consider not only current training operations, but those it may be tasked with in the future as well. For example, an installation currently supporting infantry training may want to keep open its potential for supporting noisier artillery training. An airbase with runways to support fighter aircraft may want to keep open its opportunity to extend runways to accommodate heavier aircraft in the future.

While analysis tools to predict the impact of actual or planned training or testing are readily available, they provide inadequate support for analyzing installation suitability for unknown future activities. They are good at answering the question, “If a training range is placed here, what is the pattern of the impact on the surrounding area?" They are not as useful for answering the question "Where can I consider placing a training range to minimize the impact on the surrounding area?" Instead of running an analysis of the impact of an actual or planned activity, we need to analyze the impact of regional residential areas with respect to the collective tolerance of the residents to an activity that needs to be placed in the region.

Fort Knox is one such installation identified for realignment in the recent BRAC announcement. This installation has fueled the economic development of Radcliff and Elizabethtown, two urbanized areas just south of the installation boundary. These cities were identified in Phase 1 of this project as areas growing in a manner that threatens to limit future training and testing opportunities on Fort Knox. State Roads 313 and 434 parallel the southern edge of the Fort, connecting Radcliff and Elizabethtown to Interstate 65. These roads provide the opportunity for people to settle "in the country" while supporting relative short drives to jobs in Radcliff and E-town. The LEAMluc urban development model has been used to project future settlement patterns along these routes. The question is, how will these projected patterns affect the probability of residences complaining about the training on firing ranges that exist within this area of Fort Knox?

Consider a training annoyance that is associated with a 10% rate of complaint among residents at a distance of 1000 m. An urban residential pattern is first discerned from the USGS NLCD for 2001 and is then evolved using the LEAMluc urban growth model out to the year ~2020. Using these maps and our sample annoyance training tolerance patterns, a 10% probability contour is produced for the raster results of each LEAMluc model simulation. LEAMtom, the LEAM training opportunities model (another model currently under development at ERDC/ CERL) uses the maps generated during the LEAMluc run to produce an Annoyance Tolerance Contour map for each of the scenarios we modeled. Very grossly, this Annoyance Tolerance Contour represents a 10% probability of civilian complaints being generated from an artillery training exercise on Fort Knox.

These contours are shown for the three scenarios in Figures 32, 33, and 34 respectively. The light green areas represent the Annoyance Tolerance Contour at the beginning of the simulation. Darker green represents the Annoyance Tolerance Contour after urban growth has taken place. In both cases, the contours cover those areas where Fort Knox trainers can perform artillery training with minimal risk of generating complaints from the surrounding civilian communities.

The area outside the installation shows significant new settlement locations as well as denser urban areas at the end of each simulation, especially in the Radcliff area. This loss of the low probability of complaint area along the perimeter of the installation corresponds to a significant shrinking of the area in the center of Fort Knox.

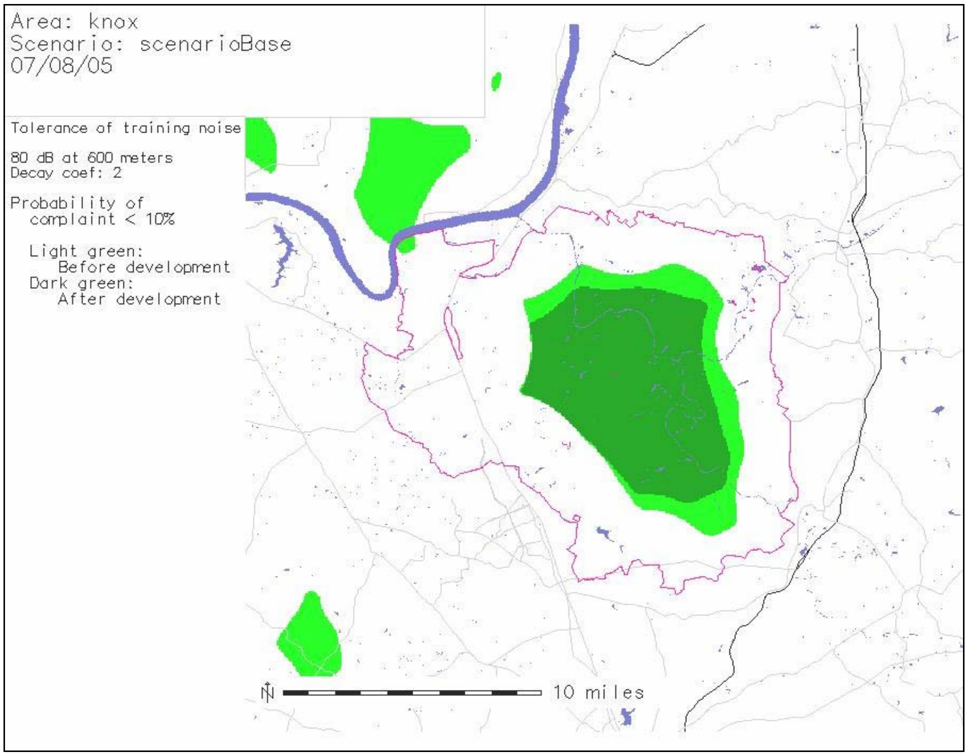

Figure 32. Annoyance Tolerance Contour for Base Scenario.

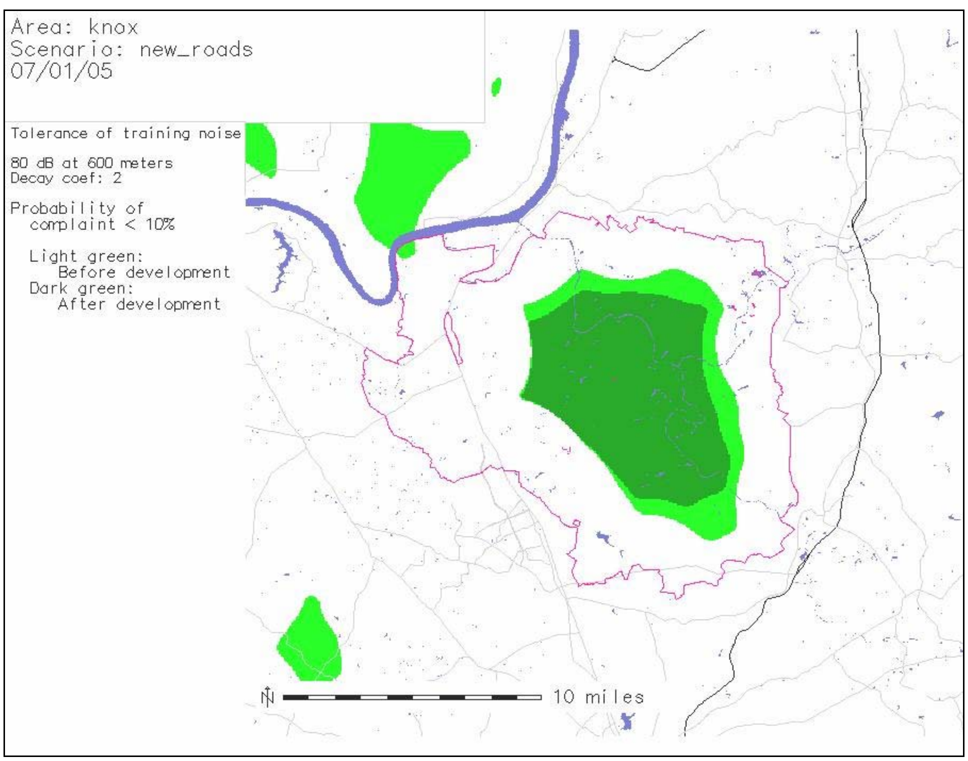

Figure 33. Annoyance Tolerance Contour for New Roads Scenario.

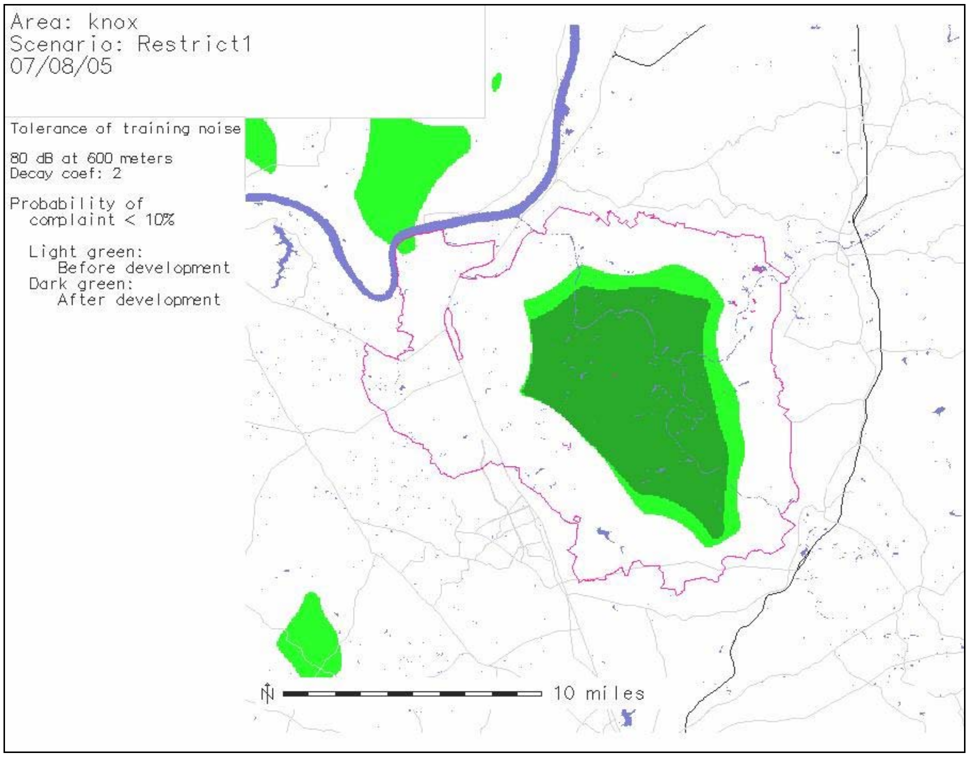

Figure 34. Annoyance Tolerance Contour for Conservation Agreement Scenario.

Note that a large portion of land deemed "safe" for artillery training purposes exists beyond the boundary of the installation before the scenario progresses. These are the large areas covered by light green in central Hardin County and across the Ohio River in Indiana. These contours do not represent lands that should be used for training purposes, but rather lands that could be used if they were available (LEAMtom does not consider the installation boundary when assessing "safe" areas on which the Army can train, therefore the entire study area is open to its interpretation). There is little to no development here and few neighbors to potentially be bothered by training activities. It should be noted that these "safe" areas disappear as each of the three scenarios runs to completion, so that by the final time step, sufficient development has occurred within them to eliminate their potential as possible training areas. In other words, these large tracts of undeveloped land to the northwest and southwest of Fort Knox will attract residential development by 2020. At that time there will likely be no land left on which the Army could train (dark green) other than that existing within the perimeter of the installation itself.

Discussion of Annoyance Tolerance Contours

Where it is possible to know the past, current, or even future location of military training and testing, it is possible to apply existing analyses and models to predict the impact of that training on surrounding natural and human areas. However, because of anticipated changes in training doctrine, weapon systems, and stationing of troops, it becomes impossible to predict the impact of future training. Instead, we have turned to predicting where training (on or off installations) could occur so as to best mitigate potential conflicts before they surface. The sample application, though not real, is realistic and indicates the ability to understand, predict, and visualize the impact of urban growth on future training and testing opportunities.

Properly calibrated, this approach will be useful for predicting future training and testing area opportunities not only with respect to noise, but to dust, smoke, and light pollution as well. Calibration will be approached in two ways. First, with respect to what we know about the physical transmission of noise, dust, smoke, and light. Such analyses can give us insights into the strength of a training annoyance, and this information must be connected to the human psychology of annoyance. Our continued research will be looking at building tables of annoyance levels and decay rates based on the annoyance itself, the local attenuating factors (environmental and structural), and human psychology. Second, calibration can be accomplished through interviews with people that have experienced the annoyances. Through interviews, we expect to collect information that allows us to correlate levels of annoyance with particular times of the day or year and establish useful working coefficients. This information would allow us to refine these annoyance tolerance contours, making them more flexible and therefore more useful to the trainers at Fort Knox.

8 Conclusions and Recommendations

Urban encroachment threatens the mission of Fort Knox to provide realistic military training to the soldiers of the United States Army. One of the goals of this study is to provide Fort Knox with options that can be taken proactively in order to mitigate conflicts between the Army and the growing civilian community that surrounds this installation.

This project used GIS map layers in an analysis of historic land use and growth in the region. These GIS layers were then used as input to the LEAMluc model to predict urban growth around Fort Knox into the future. Historical land use maps, current and future highway system plans, and municipal zoning information all contributed to forecasting residential and commercial development. But how do we use that information and what we learned to diminish the potential for future conflicts between the Army and its neighbors?

The historic trend has been a growth rate of roughly 2% per decade in the region surrounding Fort Knox. In 1972, the percent of urban development here was 1.37%. That figure grew to 6.54% in 2001 and will continue to rise as more and more of the area becomes attractive to people to build on. A closer analysis revealed that areas within a 1-mile buffer of the installation show a similar growth pattern (6.4% of this buffer was urban in 2001). When a 5-mile buffer is drawn around the installation, the picture improves slightly, with only 4.4% of this area showing urban land use. The prospect for the future, however, is that civilian encroachment around Fort Knox will only continue.

Model simulations indicate that the areas south and west of Fort Knox are those at the greatest risk for urban encroachment. The army can best avoid potential conflicts involving incompatible land use practices by examining their long-term range plan and pro-actively avoid future land use conflicts. For example, repositioning certain training assets away from the southern portion of the installation will decrease the potential for noise complaints from future residential neighborhoods. However, a better alternative would be to acquire those areas identified as the most likely to see an increased residential development before they become a problem.

A number of private land owners and NGOs such as The Nature Conservancy (TNC) and The Conservation Fund have an interest in preserving areas of native forest and wetlands in northern Hardin County, KY. Land purchases (where feasible) or conservation agreements between Fort Knox and these land holders could provide buffer zones along the installation perimeter where development would be excluded. No military training activities could be performed within these buffers, but development by the cities of Radcliff, Elizabethtown, and the surrounding communities would also be restricted.

The third simulation run in the LEAMluc model, as outlined in the section on Phase 2 of the project, was designed to see the effect such conservation agreements would have on Fort Knox. As mentioned previously in this report, the areas best suited to serve the interests of Fort Knox were determined to be just south of the installation, between its boundary line and state road 434 (Battle Training Road). There is no indication at this time that such a large tract of land could be acquired under any conservation agreements, but this is where we recommend focusing for the following reasons:

- This area is close to the southern tip of the annoyance tolerance contour we generated for this study
- Few residential neighborhoods presently exist here but the area is attractive for growth from Radcliff and Elizabethtown
- Much of this area is part of the Southeastern Ecological Framework.

This area is detailed in Figure 35.

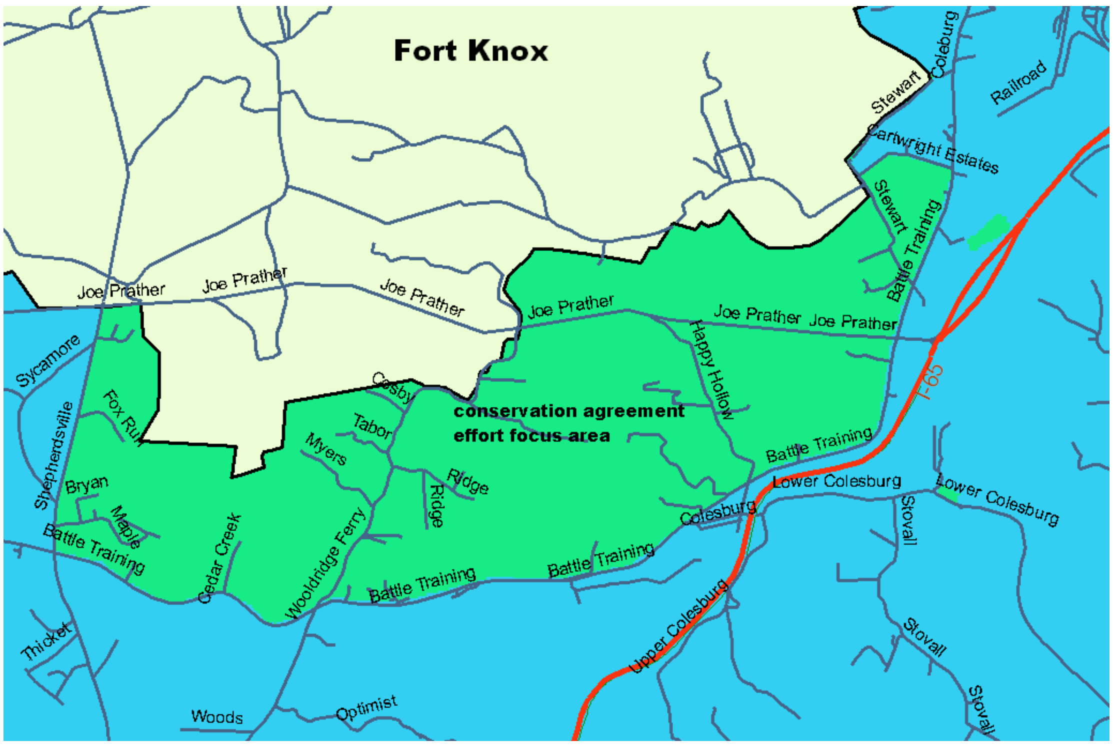

Figure 35. Detailed area of where conservation agreement efforts should be focused.

Additional recommendations on determining where Fort Knox should concentrate efforts in obtaining lands to be used as buffers against their training activities are twofold:

1. Use the Southeastern Ecological Framework Study as a starting point to identify specific tracts of land in this area that could be preserved as buffer.
2. Partner with The Conservation Fund, TNC, and other NGOs to work toward obtaining these areas through outright purchase or through cooperative conservation agreements using Army Compatible Use Buffer (ACUB) funds. An example of a conservation easement can be found by using the link in Appendix 4.

More on the Southeastern Ecological Framework Study

The southeastern United States still harbors globally significant biodiversity and other important natural resources despite decades of habitat loss and ecosystem alterations. The Southeast is also the fastest growing region in the United States. The trend appears to be driven by climate, economic stability, cultural attractions, and the natural environment. This growth will continue to deplete and degrade the critical ecological resources that remain, and it is imperative that comprehensive efforts to efficiently and effectively protect these resources are developed rapidly. This report represents exploration of a regional conservation strategy needed to conserve the integrity of ecological systems essential for human well-being.

The SEF is a decision support tool created through systematic landscape analysis of ecological significance and the identification of critical landscape linkages in a way that can be replicated, enhanced with new data, and applied at different scales. The study was conducted by the University of Florida GeoPlan Center and sponsored by the U.S. EPA, Region 4. It is intended to provide a foundation for the adoption and implementation of effective and efficient conservation measures to minimize environmental degradation and protect important ecosystem services. It has been developed for all eight southeastern states contained within the boundaries of U.S. EPA, Region 4: Florida, Georgia, South Carolina, North Carolina, Alabama, Mississippi, Tennessee, and Kentucky.

The land area identified in the Framework represents 43 percent of the land in the eight states. Of that 43 percent, 22 percent is in existing conservation lands, 12 percent in open water (rivers, lakes and reservoirs), 14 percent is in wetlands outside existing conservation lands and 52 percent is in privately held uplands (that include 100 year floodplains). Fort Knox itself is one of the hubs in the Framework. For a PDF copy of the SEF study final report, click here: SEF final Report.

The Conservation Fund

The Conservation Fund assists local, state, and federal agencies, and nonprofit organizations acquire property from willing sellers to protect open space, wildlife habitat, public recreation areas, river corridors, and historic places. The Fund also works with communities as well as different sectors of industry, including forest and chemical companies, developers, and ranchers to demonstrate sustainable practices that balance economic and environmental goals. Clearly the goal of Fort Knox is to preserve the current quality of training it now offers to the soldiers of the U.S. Army. In partnering with the Conservation Fund to identify and protect these areas, Fort Knox has the opportunity to preserve areas that could act as a buffer, but could also serve as wildlife habitat, recreation areas, and wetland. The Fund also serves as a national resource for environmental organizations by providing financial resources and technical assistance in protecting these ecologically significant lands.

Contact information for the Conservation Fund:
The Conservation Fund
National Office
1800 North Kent Street, Suite 1120
Arlington, Virginia 22209-2156
Phone: 703-525-6300
Fax: 703-525-4610
postmaster@conservationfund.org

Army Compatible Use Buffer Program

In 1995 stakeholders in and around Fort Bragg began concerted efforts to address a common issue, the management and restoration of the endangered Red-Cockaded Woodpecker (RCW). Fort Bragg and the nearby Sandhills Area game lands host the second largest surviving RCW population. These two areas are separated by a collection of private lands into two subpopulations. In discussions of how to best manage the RCW, it became apparent that private lands would be a critical part of recovering their population.

Cooperative efforts to conserve private lands for the benefit of the RCW became known as the North Carolina Sandhills Conservation Partnership and what the Army called the Fort Bragg Private Lands Initiative (PLI). The fundamentals of PLI include partnering with local stakeholders to buy lands or interests therein from willing sellers. The partner holds the land or interest therein while the Army receives the benefit of open space in the vicinity of its installations. These lands can then be used to buffer the installation from incompatible development and conservation of habitat in ways that protect activities on the installation from being restricted.

Environmental restrictions, incompatible development, and other factors that affect military training and readiness are collectively termed encroachment. Since the implementation of PLI at Fort Bragg, the Army has found the same approach applicable to encroachment problems at installations across the nation. In implementing PLI, the Army had operated under the Sikes Act authority to enter into cooperative agreement for conservation purposes. Section 2811 of the 2003 Defense Authorization Act, codified at 10 USC 2684a, reaffirmed and expanded this authority to include constraints on military training, testing, and operations.

Subsequent to the enabling legislation in the 2003 Defense Authorization Act, the Army produced a policy guidance memorandum describing how to implement ACUBs, which are defined as formal agreements between Army and eligible entities for acquisition by the entities of land or interest in land and/or water rights from willing sellers. Camp Blanding was the first Army installation to establish its own ACUB program under the new legislation and guidance followed by Fort Carson and Camp Ripley. Because of the mutual interests served, the Fort Bragg PLI approach has caught on not only in the Army but also with conservation organizations, states, and local governments.

Appendix 4 of this report is the legislation and guidance for the ACUB program.

For more information, go to http://www.sustainability.army.mil/acub.htm#30

Ownership Information for Parcels Within a 5-mile Buffer of Fort Knox

One of the tasks identified for this project, but not in the original scope of work, was to obtain, in GIS shape file format, a list of property owners along with their contact information for all parcels of land within a 5-mile buffer of Fort Knox. This would include portions of Bullitt, Hardin, Meade, Nelson and Jefferson counties. We were able to acquire parcel information for a portion of Hardin County we were interested in, and some larger scale zoning information for Meade County. However, neither of these datasets had the required ownership information. After exhausting all other potential sources for this information, we did locate a database, run by the Kentucky Department of Revenue, which supported the information we were looking for. The cost of this data, however, would have been one fifth of the budget for the entire project, which effectively prohibited us from obtaining the data. This information would be useful in pursuing the conservation agreements we have discussed. Therefore, it is recommended that, if Fort Knox is able to find the necessary funds (approximately $10K), they contact the Kentucky Department of Revenue to obtain this data. The point of contact is:

Patti Hall
Technical Support
KY Dept of Revenue
502-564-8334
Patti.Hall@KY.gov

Additional Recommendations

Since the availability of high-resolution imagery for installations such as the 0.3-m imagery provided by Fort Knox is expected to become more common, it is recommended that new research be implemented in order to address the issue of pattern recognition analysis in high resolution imagery for GISs. We could then use the 0.3-resolution aerial imagery from 2005 to refine the growth curve for historic urbanization in the region. This research would allow us to better understand and extrapolate the trend into the future for a more accurate picture of what development might look like around Fort Knox in the years to come. GRASS GIS would be a good research package because its open structure would make the development easy, and it already has the initial software to build upon.

Additional work should also be done in refining the annoyance tolerance contours for Fort Knox. Properly calibrated, this approach will be useful for predicting future training and testing area opportunities not only with respect to noise, but to dust, smoke, and light pollution as well. Continued research would look at building tables of annoyance levels and decay rates based on each annoyance, the local attenuating factors (environmental and structural), and human psychology. This work would be accomplished through personal interviews with people that have experienced the annoyances in order to correlate levels of annoyance with particular times of the day or year.

Another area that should be investigated for opportunities in cooperative agreements between Fort Knox and local land holders is the area to the west of the installation in Meade County. This part of the Ohio River Valley is currently in agricultural production. Urbanization is minimal here today. A number of residential pockets are occurring there, but simulations using LEAMluc forecast increased residential development in the area. We did not model this scenario, but felt the area warranted further investigation into the possibility of cooperative agreements between farmers and the Army. NRCS or some other agricultural agency or organization may have ideas on how this could be accomplished.

References

Clarke, K.C. and L. Gaydos. (1998). "Long term urban growth prediction using a cellular automaton model and GIS: Applications in San Francisco and Washington/Baltimore." *International Journal of Geographical Information Science*.

Corporation, A. (1997). "Ground Cloud Dispersion Measurements during the Titan IV Mission #K22 (12 May 1996) at Vandenberg Air Force Base; Volume 1-Test Overview and Data Summary." 104.

Court, A.T. (1939). Hedonic Price Indexes with Automotive Examples. *The Dynamics of Automobile Demand*. New York, General Motors Corporation**:** 99-117.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. (1979). Classification of Wetlands and Deepwater Habitats of the United States, Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C.

Deal, B., and Z. Sun. (2005). A Spatially Explicit Urban Simulation Model: The Land-use Evolution and Impact Assessment Model (LEAM). *Regional Development, Infrastructure, and Adaptation to Climate Variability and Change*, Springer:New York.

Deal, Brian M., Donald F. Fournier, Diane M. Timlin, and Elisabeth M. Jenicek. (2002). Technical Report ERDC/CERL TR-02-27/ADA409139, U.S. Army Engineer Research and Development Center:Champaign, IL.

Department of Defense. (2005). "Base Realignment and Closure 2005" http://www.defenselink.mil/brac/vol_I_parts_1_and_2.html

Durbrow, B. Richard, Neil B. Burns, John R. Richardson, and Cory W. Berish. (2001). “Southeastern Ecological Framework: A Planning Tool for Managing Ecosystem Integrity,” Proceedings of the 2001 Georgia Water Resources Conference, J. Hatcher, editor, Institute of Ecology, University of Georgia, Athens, GA.

Elvidge, Christopher D., Ramakrishna Nemani, James E. Vogelmann, V. Ruth Hobson, Benjamin Tuttle, Jeff Safran, Ingrid Nelson. (2001). “Development Sprawl Impacts on the Terrestrial Carbon Dynamics of the United States,” annual report for NASA Land Cover/Land Use Change Research Program.

Finegold, L.S., C.S. Harris, et al. (1994). "Community Annoyance and Sleep Disturbance: Updated Criteria for Assessing the Impacts of General Transportation Noise on People." *Noise Control Engineering Journal* 42(1): 25-30.

Franklin, A.G. (1980). "Interpretation of Data from Uphole Refraction Surveys." Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS. Technical Report MP-GL-80-5. 73.

Goran, W.D. (1989). "Testing Guidelines for GRASS Ports and Drivers." Technical Report CERL-N-89/22. U.S. Army Construction Engineering Research Laboratory, Champaign, IL.

Haas, C.G. (1922). “Sale Prices as a Basis for Farm Land Appraisal,” Technical Bulletin, University of Minnesota.

Hosmer, D.W., and S. Lemeshow. (1989). Applied logistic regression. Wiley:New York, NY.

Kelly, P.M., and J.M. White. (1993). Preprocessing remotely sensed data for efficient analysis and classification, Applications of Artificial Intelligence 1993: Knowledge-Based Systems in Aerospace and Industry*, Proceedings of SPIE*, 24-30.

Lacey, R.M. (2001). "Land Use Planning and Sustaining the Military Land Base." Special Report ERDC/CERL SR-01-8, ADA395084. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

Little, Violet I., and David L. Effland. (1981). "Blast Noise Prediction. Volume II. BNOISE 3.2 Computer Program Description and Program Listing." Vol. 2: 256.

Lozar, R., W.D. Meyer, J.D. Schlagel, R.H. Melton, B.A. MacAllister, J.S. Rank, D.P MacDonald, P.T. Cedfeldt, and P.M. Kirby. (2005). “Characterizing Land Use Change Trends Around The Perimeter Of Military Installations.” Technical Report ERDC TR-05-4, Champaign, IL. Total Army Basing Study (TABS), Modeling Support Team ASA-IA.

Lozar, Robert C., and Richard Schneider. (2005). “Ambient Light Encroachment at Military Installations.” Technical Note ERDC/CERL TN-05-2. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

Pater, L. W., Pamela Woof, Diane Rhoads, and Michael White. (1999). "Getting Started Guide for the Small Arms Range Noise Assessment Model (SARNAM)." CERL ADP Report 99/48, ADA364860, U.S. Army Construction Engineering Research Laboratory, Champaign, IL.

Ralston, J.M., J.F. Heagy, and R.J. Sullivan. (1998). “Environmental Noise Effects on VHF/UHF UWB SAR,” *Proc. European Conference on Synthetic Aperture Radar, EUSAR'98*, Friedrichshafen, Germany, pp 141-144.

Saaty, Rozann. (1996). "The Analytic hierarchy process and utility theory: Ratio scales and interval scales," Proceedings of the Fourth International Symposium on the Analytic Hierarchy Process, Simon Frasier University, Burnaby, B. C., Canada, July 12-15, pp 22-27.

Schkade, D., and J. Payne. (1993). "Where do the numbers come from? How people respond to contingent valuation questions," *in* J. Hausman, ed., *Contingent Valuation: A Critical Assessment*, North Holland: Amsterdam.

Schomer, P.D., L.R. Wagner, and L.J. Benson. (1995). "Human and Community Response to Military Noise. Results from Field- Laboratory Tests of Small Arms, 25 mm Cannons, Helicopters, and Blast Sounds." CERL Technical Report 95/07, ADA301394. U.S. Army Construction Engineering Research Laboratory, Champaign, IL.

Schultz, T.J. (1978). "Synthesis of Social Surveys on Noise Annoyance." *J. Acoustic Society of America* 64: 377-405.

Sirmans, G. Stacy, David Macpherson, Lynn MacDonald, and Emily Zietz. (2005). “Composition of Hedonic Pricing Models,” *Journal of Real Estate Literature*.

Sutton, P., D. Roberts, C. Elvidge, and H. Meij. (1997). A Comparison of Night-time Satellite Imagery and Population Density for the Continental United States. *Photogrammetric Engineering and Remote Sensing*, 63(11), pp 1303-1313.

U.S. Environmental Protection Agency. (2000). Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns. U. S. EPA, National Exposure Research Laboratory.

U.S. Environmental Protection Agency. (1972). Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare With and Adequate Margin of Safety, U.S. EPA.

Vogelmann, J.E., T. Sohl, and S.M. Howard. (1998). "Regional Characterization of Land Cover Using Multiple Sources of Data." *Photogrammetric Engineering & Remote Sensing*, Vol. 64, No. 1, pp 45-47.

Vogelmann, J.E., T. Sohl, P.V. Campbell, and D.M. Shaw. (1998). "Regional Land Cover Characterization Using Landsat Thematic Mapper Data and Ancillary Data Sources." *Environmental Monitoring and Assessment* 51: 415-428.

Wallace, H.A. (1926). “Comparative Farmland Values in Iowa.” *Journal of Land and Public Utility Economics* 2: 385-92.

Appendix 1: Detailed Procedure To Generate Historical Urbanization From LANDSAT Imagery

Required Software

ESRI ARCGIS 8.1 with extensions Spatial and Image Analyst
ERDAS Imagine8.6
MicroSoft Excel
WinZip.

Required Data

North American Land Cover (NALC) data for Fort Knox
NLCD maps of land use for 1992 and 2002
Installation Boundaries
Roads from Census data
For Contextual Information
Urban Areas
Road network
Recent installation boundary map (.shp file)

Step 1: NALC Imagery

Step 1 general description: With the NALC Imagery already acquired, set up a working **ArcMap** Window. Mosaic and subset.

Make a directory entitled "Historic" in the Fort Knox directory.

Set up context

A set of standard contextual data from which we started is the **Knox_Nalc_Analysis.mxd.** This brings up an **ArcMap** window with contextual data.

Create study area

As closely as possible the study area needs to coordinate with the LEAM study area, which are the surrounding counties:

KY: Jefferson, Meade, Bullitt, Breckinridge, Hardin, Nelson, and Larue
IN: Clark (portion), Harrison, and Floyd

NALC imagery tiles cover Fort Knox

To cover the maximum area available with the NALC images, for each decade, two images are used. This is to allow coverage of both Louisville and the installation.

1970s: 020034_70_2.img & 021034_70_2.img
1980s: 020034_80.img & 021034_80.img
1990s: 020034_90.img & 021034_90.img

Merge NALC images

In Imagine, use the Mosaic tool to Mosaic the images into one:

Subset the portion of the mosaic to the study area:
Define subset of the 5-mile buffer as an **AOI**

1. Open two Viewers. In Viewer #1 display the **DecadeX.img** for the installation.
2. In Viewer #2, first display the **DecadeX.img** (this ensures that the projections in both viewers are the same), then display the vector layer **Study_area_historic,** from which you want to create the AOI. Images in Viewer #1 must be in the same map projection as the **Study_area_historic** vector file in Viewer #2.
3. In Viewer #2, select (click on, then shift & click) all of the counties of the **Study_area_historic** file. The **Study_area_historic** turns the selection color (probably yellow).
4. In the menu bar of Viewer #1, select **AOI | Copy Selection to AOI...**
5. In the menu bar of Viewer #1, select **View | Arrange Layers.** In the **Arrange Layers Viewer #1,** right click on the AOI layer and choose **Save layer.** In the **Save AOI as:** window, navigate to the **historic directory** and save it as **study_area_historic.aoi.** Click **OK,** then **OK** again to dismiss the **Save AOI as:** window.

Subset the portion of the mosaic to study_area_historic.aoi:
Under the **Data Preparation** menu item, click the **Subset Image** option**.**

In the Subset Image Tool window:

For the **Input File Name** navigate to the **historic** directory, choose the image **DecadeX.img.**

For the **Output File Name,** navigate to the **historic** directory, save as Files of type: **Image**, and name the new image **Decade_mos_stud.**

For the **Data Type** set:

Input: Unsigned 8 bit

Output: Unsigned 8 bit

Output: Continuous

For Output Options set

Select Layers: 1:3
Click on the **AOI** button on the bottom.

In the Choose AOI window, Select an AOI Source: click on AOI File option.
In the **Select the AOI File** box, navigate to the installation directory, and choose the **study_area_historic.aoi** file. Click **OK.**
Press the **OK** button to start the sub setting.

Ensure all images and vectors are in the projection of the NALC imagery . The official projection for all work on this project is Coordinate System:

Transverse_Mercator Zone 16
False_Easting: 500000.000000
False_Northing: 0.000000
Central_Meridian: -87.000000
Scale_Factor: 0.999600
Latitude_Of_Origin: 0.000000
GCS_WGS_1984
Datum: D_WGS_1984
Prime Meridian: 0.

The projection of all data frames should be in this projection. All data bases generated should also be in this projection because when using Spatial Analyst, unexpected results can be derived when generating new maps. (ArcGIS8.3 does projections FOR DISPLAY on the fly. FOR ANALYSIS, it is best to generate information in the native projection of both the originating data and the frame.)

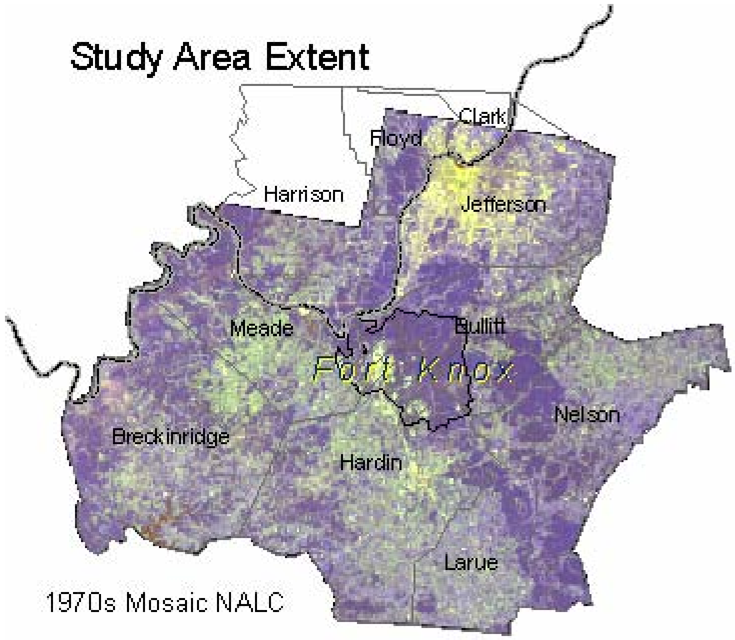

Figure 1-1. NALC imagery over study area.

Step 2: Generate "Urban" Land Cover From the NALC Images

Step 2 general description: Since urban areas usually do not disappear over time, we clip out any locations that were not urban in 2001. We need to determine from the imagery the locations that are most likely urban. To do this we run the image through an unsupervised classification routine. From this image, we choose those categories that best fit urban. Using this urban definition as a mask, we do another unsupervised classification but only on those areas that are most likely to be urban.

1. Extract the urban categories from the 2001 NLCD data
2. Turn the classes determined to be urban into a grid mask.
3. Use an Unsupervised classification with 16 or 100 categories to generate a classified image of land cover from IKONOS image for the study area.

Extract the urban categories from the 2001 NLCD data. In **ArcGIS**, reclass the NLCD urban categories (21, 22, 23) to 1 and call the result **nlcd_20_urb1**. Convert the grid to a vector file, **nlcd_20_urb1** (do not generalize).

Using Imagine

There are several reasons for generating a mask of urban land uses in about 2001. First, it will provide a conservative evaluation of the encroachment that is occurring. Although by this restrictive technique, we may miss areas that were “urban” in 1992, we end up counting as urban only those areas that are included in the 2001 “urban” mask. That is, for our 1992 urban value, we will count only those areas that were urban in both 1992 and 2001. Second, this also ensures a single direction for development (i.e., greater development as time goes on).

In order to implement these concepts, we fine-tune the identification of the 2001 urban areas. In general the procedure is to develop a mask from the most urban categories above, then let the unsupervised classifier reclassify only those areas in the urban mask. By testing each of the resulting categories, the researcher determines the best dividing line between categories that are urban and non-urban.

On the **ERDAS Imagine8.6** main tool bar click on **Image Interpreter**: the select **Utilities** then **Mask**. In the Mask window,

For the **Input File**: navigate to the **Historic** directory and select **Decade_mos_stud.img**.

For the **Input Mask File**: navigate to the Historic directory, change Type to **GRID** and select **nlcd_20_urb1**. Check the attributes are set correctly by clicking on the **Setup Recode…** button.

In the **Thematic Recode** window, there should be two lines where the **Value 0** represents areas to be dropped out of consideration and the **Value 1** are those to be retained. If this looks ok, click the **OK** button.

For the **Output File**: navigate to the **Historic** directory and enter **Decade_nlcd_20_urb1_masked.img**. Put a checkmark in the **Ignore Zero in Output Stats** box. Press **OK** to launch the process.

On the main toolbar click the **Classifier** button. On the **Classification** menu, choose **Unsupervised Classification**.

In the Unsupervised Classification (Isodata) window for the Input Raster File navigate to the Historic directory and choose **Decade_nlcd_20_urb1_masked.img**. For the Output Cluster Layer, navigate to the Historic directory and for Files of type: enter GRID Stack (*.stk) then for File name: enter **Decade_I_class16_g**. Uncheck the Output Signature Set box. For Number of Classes, enter 16.

Take the defaults for the rest:
Initialize from Statistics
Maximum Iterations: 6
Convergence Threshold: 0.950
Skip Factors: x=1, y=1

Press **OK** to run the classification.

Warning boxes may appear. Just click **OK** so the processing can continue.

Examine **Decade_I_class16_g** closely. You should see output for only those areas that were previously designated as roughly urban. In the **Decade_I_class16_g** determine which classifications best coordinate with real urban areas and still pick up as little barren land as possible. Normally the “lighter” or higher number categories are the most truly urban, while the “darker” in this classified image tend to be the barren areas. As a rule of thumb, the lighter few categories will best represent true urban. It is recognized that some barren areas will still be included in this delineation of urban, but the technique should divide the two categories well.

Use ArcGIS to assign colors to urban classes and transparent to those that are not yet developed. Each decade should show an increase in built upon lands, so compare the classifications between decades to ensure that the classes chosen for urban increase in aerial coverage over time.

Appendix 2: Detailed Implementation of LEAMluc

The following procedures were implemented within the Geographic Resources Analysis Support System (GRASS), a UNIX-based geographic information system (GIS). Instead of a single long script that would run the required GIS commands, the UNIX make program was used. This program reads a "makefile" that contains pairs of dependent and independent file (map) names followed by instructions that process the independent maps into the target dependent map. Entries in the make-file for any of the independent maps as dependent maps make it possible to describe an entire hierarchy of dependencies. The make program reads the file and checks create date time stamps on the target files to identify which processes, if any, need to be run to make sure the final target map is up-to-date. Commands used to process the independent maps in one of the pairs were combinations of UNIX and GRASS raster GIS commands.

The developed analysis focused on the attractiveness to future residential development using the following primary hedonic attractor maps:

- Driving time (minutes) to nearest state highway
- Driving time to nearest county road
- Driving time to the nearest county and/or state highway intersection
- Driving time to nearest limited access highway on-ramp
- Driving time to nearest very high density, high density, and medium density areas
- Distance to nearest neighborhood water and forest
- Density of surrounding neighborhood
- Slope of the land

Analysis started with a set of maps readily available for any location in the United States:

- Land Cover – USGS NLCD maps
- Digital Elevation – USGS DEM
- Road Network – Census bureau Tiger files

Virtually all processing was done at a spatial resolution of 30 m, which is close to the resolution of most of the input data, size of a residential lot, and width of a road.

The driving time maps were generated using the GRASS r.cost cumulative cost analysis program. The location of very high, high, and medium density areas were automatically generated based on the NLCD maps. Commercial cells (NLCD category 23) were given a value of 2, residential (categories 21 and 22) a value of 1 and all other cells a value of 0. A neighborhood filter that weighted the influence of closer cells more highly than more distant ones was passed through the map to assign a neighborhood density value to every cell. The "peaks" in this file were then isolated, which represented density centers. These were then divided into four levels: very high, high, medium, and low. This automated process identifies actual locations of higher density areas that were used as attractor points to surrounding areas. The driving times for every cell to the nearest very high, high, and medium density center were calculated as three of the attractors.

Driving times to the nearest state highway, county road, intersection, and limited access highway were also calculated using the r.cost program. (For our purposes, the standard GRASS r.cost program was modified to accommodate the notion of non-intersecting crossing roads (e.g., a local road crossing an interstate highway). The logs of all driving times were then taken for further comparison with where development exists.

Distance to the nearest water and forest were simply calculated as the straight-line distance less than 150 m. Greater distances were simply assigned the value of 150 m.

To capture the notion of residential area development being attracted to existing residential development, a density of surrounding residential neighborhood map was created using the GRASS r.mfilter program. Closer residential areas carried more weight than more distant areas.

Next the individual attractor maps were each compared with the pattern of residential development found in the NLCD map. For each attractor map, the following procedures were applied. First the map was transformed into an integer map from 0-20 to create the 20 ranges or bins. This result was cross-tabulated with the NLCD map to identify the number of locations (in each bin) that are and could be developed. This resulted in a graph that allows conversion of the attractor map to a probability of having a residential area. This procedure generates a set of residential probability maps — each having a range not extending beyond the range of 0 to 1.0. Those attractors that correlate strongly with residential areas have larger ranges of correlation values than those that do not.

The values from the various attractor maps are averaged for each location (cell) to generate a summary attractiveness map — effectively grouping locations together into sets of similar overall attractiveness. Finally, these sets must be linked with real probabilities of being associated with residential areas through the application of the process described above. A series of 20 subranges are established and cross-tabulated with residential and potential residential areas to associate each bin with a likelihood or probability of being residential. Finally, the derived relationship is applied to the summary attractiveness map to create a map of the probability of residential development around Fort Knox.

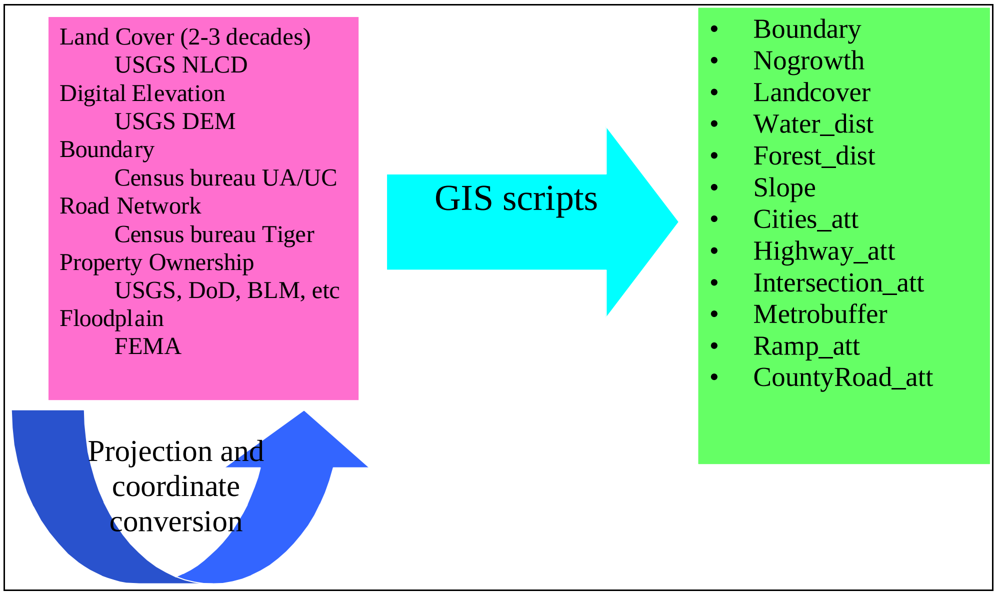

Figure 2-1. Computer and human steps.

Most of the required data manipulation was also completed in the provided data. We then manipulated the data to create a set of standard maps that could then be automatically processed in the final step. The raster maps needed must all be in the same projection and resolution and have the following contents:

SMALL_CITY - Location of "small cities"
  0 No small city
  1 Small city
MED_CITY - Location of "medium cities"
  0 No small city
  1 Small city
LARGE_CITY - Location of "large cities"
  0 No small city
  1 Small city
NO_GROWTH - Explicit identification of areas of no growth
  0 No restrictions
  1 No growth areas
DEM
  Categories are meters above sea level
MUNICIPAL_BOUNDARY

City boundaries

STUDY_AREA
- 0 Outside study area
- 1 Inside study area

ROADS
- 0 No road
- 1 Limited access highway
- 2 Federal highway
- 3 State highway
- 4 County road
- 5
- 6 Ramps
- 7 Private road

LANDCOVER - NLCD Landcover Map

11 Open water
12 Perennial Ice/Snow
21 Low Intensity Residential
22 High Intensity Residential
23 Commercial/Industrial/Transportation
31 Bare Rock/Sand/Clay
32 Quarries/Strip Mines/Gravel Pits
33 Transitional
41 Deciduous Forest
42 Evergreen Forest
43 Mixed Forest
51 Shrubland
61 Orchards/Vineyards/Other
71 Grasslands/Herbaceous
81 Pastures/Hay
82 Row Crops
83 Small Grains
84 Fallow
85 Urban/Recreational Grasses
91 Woody Wetlands
92 Emergent Herbaceous Wetlands

A GIS script processes these maps automatically. This script was based on ArcGIS scripts used to develop input maps for the LEAMluc simulation program. We captured and adapted the ArcGIS scripts in the form of a “makefile” to drive processing with the GRASS GIS. GRASS is a public domain GIS that was developed to work hand-in-hand with UNIX commands. A makefile is processed by the Unix make program and is composed of a series of target-dependent statements, each of which is followed by instructions for creating the target from the dependents. When the make program is invoked, it reads a makefile in the current directory and makes sure that all dependents have more recent creation dates than their dependents.

These scripts make it possible to modify one input and only the dependents that are directly and indirectly dependent on that input are recreated.

This script processes the maps manually developed though the steps outlined in Figure 2-2. The maps on the left are the manually developed maps. Those in green are the maps that can be provided to the LEAMluc model for generating possible development pattern futures. Those in orange are 0-1 scale index maps that capture the probability of a residential area currently associated with the particular characteristic. For example, if a location has a slope of 15 degrees, the value associated with that location in the Slope Index map is the probability across the map of a residential area of 15 degree slope supporting a residential area. The final map, ATTRACTOR_RES, is the result of combining all of the index maps to create a map representing the attraction of each location to residential development.

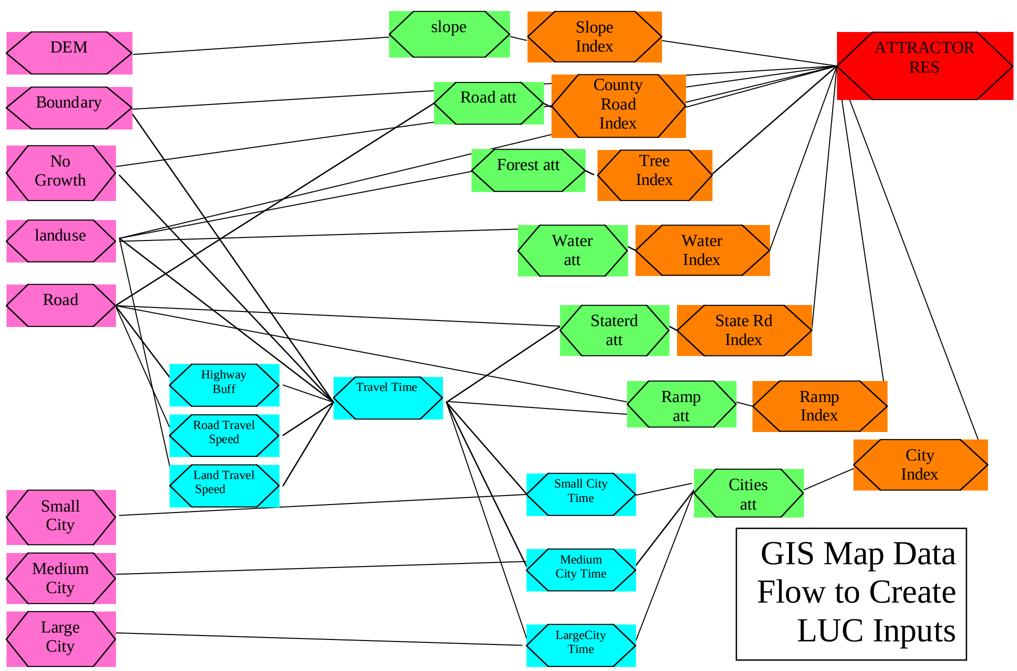

Figure 2-2. Simplified map transformations.

Many of the index maps consider travel time to such things as roads, highways, intersections, and cities. The most time-consuming GIS operations involved in developing inputs are the necessary cumulative distance analyses (the GRASS r.cost command). To improve the processing time by a factor of almost 50x, the r.cost command was modified for this project and resubmitted to the GRASS shareware community.

Each of the index maps is a transformation of the associated input map created as follows. The current land use map is processed to select 1) locations where residential areas exist and 2) locations where residential areas could develop. The input map (e.g., slope) is cross-tabulated with the GRASS r.coin program, which generates an array of numbers indicating the number of locations associated with each combination of the input map and the residential location and potential location map. For each input category, the probability of finding a residential location is then calculated by dividing the number of residential areas by the sum of the number of residential and potential residential areas. This calculation results in a localized graph for each input map (Figure 2-3) that is used to convert input map categories to index maps. This transformation is accomplished with a modified version of the GRASS r.mapcalc program, which allows users to write equations using maps and a variety of builtin functions (e.g., mapA = mapB * mapC). The modification allows expressions like:

MapB = graph(MapA, x1,y1, x2,y2, x3,y3)

Any number of x,y pairs can be given and x must be increasing through the series.

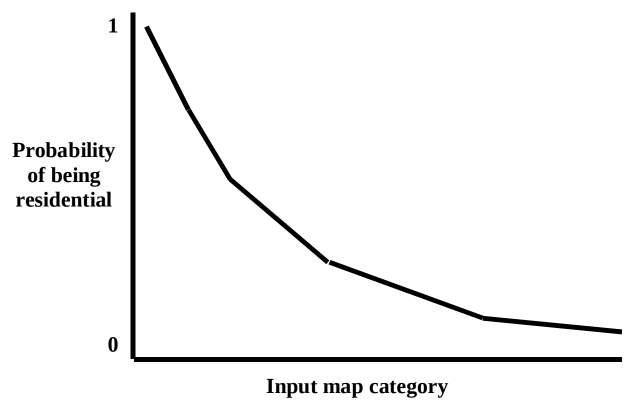

Figure 2-3. Probability of being residential.

Although all graphs can be very different from one another, the total area under each graph will be constant as it represents the total proportion of potential residential sites that are residential. Some graphs will be relatively flat indicating little preference for that particular attractor while others will favor some part of the input category range (e.g., slopes below 15% or areas closest to cities).

The final step is to combine the various index maps to form a composite index. The indices can be either summed or multiplied. We chose to sum the indices and divide by the total number of indices to guarantee arrival at a composite value between 0 and 1. The more general form of this approach is to multiply each index by a calibration coefficient, sum the results, and divide by the sum of the coefficients. There is a self-calibration that allows for automatic calibration coefficients of 1. Those graphs that indicate little or no preference are automatically discounted by the fact that their indices are relatively constant. Therefore, the final residential attractiveness map is computed using the GRASS r.mapcalc program.

Appendix 3: Detailed Approach to Generating Annoyance Tolerance Contours

Our objective was to identify where an activity associated with an annoyance that radiates away from that activity could be located to minimize the potential of complaint from receptors of that annoyance when the locations of receptors are known or given. Let us consider first a single receptor; perhaps a single-family residential house. We are given the fact of a known decibel level at a known distance and need to convert this information to a pressure level. Decibel level is calculated from a pressure level according to **Equation 1**. Solving for E when the dB level is known yields **Equation 2**. For example, if a particular aircraft noise at 200 meters is 110 dB, the pressure level (E) at that distance is $(10^{110/10} \text{ x } 20^2)^{1/2} = 6{,}324{,}555\ \mu\text{Pa}$

Equation 1

$$dB = 10\log_{10}\left(E^2 \mu Pa / 20^2 \mu Pa\right)$$

Equation 2

$$E = \left(10^{dB/10} \times 20^2 \mu Pa\right)^{1/2}$$

Sound, for example, can dissipate up and away in all directions from its source in a dome shape. The surface of that dome is proportional to the square of its radius, the distance from the source. If the sound energy is spread evenly across that dome, the strength of that energy at any point on the landscape is represented by **Equation 3**, where E is the energy level, E_1 is a constant representing the intensity of that energy at unit distance 1, and D is the distance from the source. Note that this assumes no absorption of the energy by air or ground and that frequency is irrelevant.

Equation 3

$$E = E_1 / D^2$$

E_1 can be calculated by substituting the result of **Equation 2** and the given distance into **Equation 3**, leaving us with the ability to predict the intensity of the sound pressure at any distance between receptor and emitter. For our example of a 100 dB noise at 200 meters, E_1=6.3E6 x 200^2 = 252E9. Using these values, the relationship between energy and distance can be generated (Figure 1).

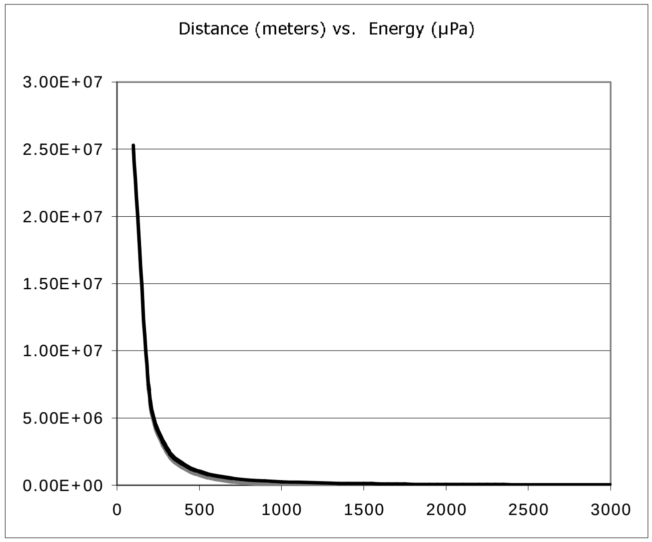

Figure 3-1. Energy decreases with distance.

The goal is to convert the sound energy levels to a probability of complaint, which involves estimation of the probability of annoyance. The human ear perceives sound energy logarithmically and a decibel (dB) logarithmic scale has been developed for practical communication of sound intensity. Therefore, conversion of the sound energy to dB is appropriate for associating an annoyance factor with the sound. By convention, the reference sound pressure for the log scale is 20μPa (micro Pascals). The conversion from sound pressure (E) to dB is given by **Equation 4**, which is a restatement of **Equation 2**.

Equation 4

$$dB = 10\log_{10}[E^2/20^2]$$

Figure 3-2 displays the result of applying this conversion to the sound pressure information in Figure 3-1.

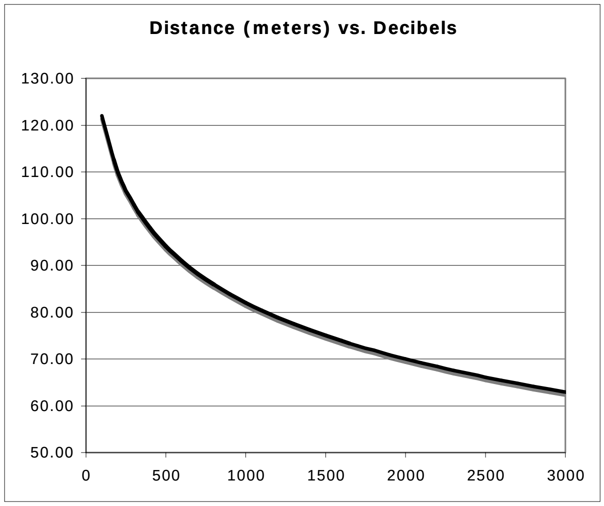

Figure 3-2. Decibel Level vs. Distance

Where the location of the noise generation is known or planned an analysis can proceed to identify the associated decibel contours to identify potential conflicts with other landuses such as residential. For example, residential areas are generally considered tolerant of DNL levels of 65 dB and below and levels of 55dB or less are associated with no adverse impact (U.S. Environmental Protection Agency 1972).

In this case, however, the location of the receptors are established rather than the noise and the goal is to identify options on the landscape where a noise generating activity might be located. Therefore, the sound level must be converted into an annoyance value that can be used as a probability of complaint. Schultz (1978) showed a consistently reported correlation between dB levels adjusted for day-night (L_{dn}) and annoyance that is represented by **Equation 5**. This relationship was affirmed by Finegold et al. (1994).

Equation 5

$$P = 0.8553L_{dn} - 0.0401L_{dn}^{\ 2} + 0.00047L_{dn}^{\ 3}$$

Plugging in the result of **Equation 4** into **Equation 5** gives us the ability to predict the percent of highly annoyed individuals from a community at a given distance from an activity described by the combination of a decibel value at a known distance (Figure 3-3).

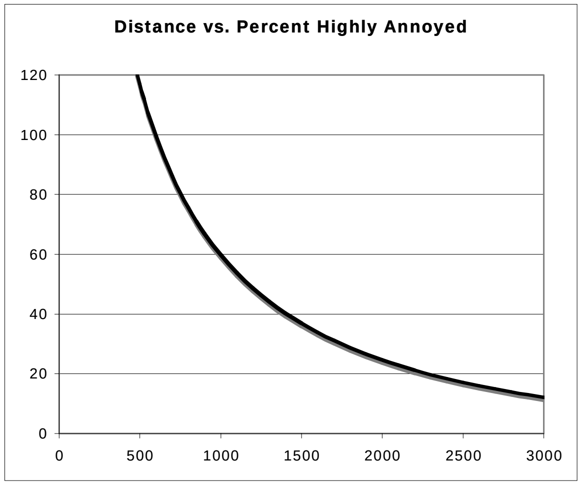

Figure 3-3. Percent Highly Annoyed vs. Distance.

Reconsider now the squared power (in **Equation 3**) that captures the notion of a dissipation of the annoyance over a three-dimensional (3-D) expanding dome. In some important cases dissipation is not 3-D, but rather 2-D. For example, in the situation of a temperature inversion, which can frequently occur in late sunny afternoons over dark ground, noise energy is refracted by the atmosphere back to the ground (REF). Hard ground cover such as rock, sand, or water can then bounce the sound energy. When combined, sound energy can radiate in a manner that is captured with a coefficient approaching 1. Conversely, ground effects involving vegetation can absorb sound energy at certain frequencies and energy associated with higher frequencies will be absorbed by the atmosphere. Such effects can be captured in our equations by using coefficients larger than 2.

Implemented within a raster GIS, it is now possible to assign every grid cell a probability of highly annoyed individuals based on the location of a single receptor and the probability of complaint at some given distance. Now, let us consider the case where there are multiple receptors (multiple residences for example) of the potential annoyance on the landscape; e.g. multiple residences. Annoyance probability surfaces can be generated for each receptor and then combined. Consider a location where the probability of complaint by each receptor is 50% (P_1=.5, P_2=.5). Half of the time at least the first receptor will complain and half of the remaining time the second receptor will complain resulting in a probability of 75% (0.75)that at least one will complain. Mathematically this can be calculated generally as follows:

Equation 6

$$P = 1.0 - \prod_{i=1}^{n} (1.0 - P_i)$$

P_i represents the probability of calculated complaint probabilities by one of the receptors.

Implementation

These equations were implemented with the Geographic Resource Analysis Support System (GRASS) (Goran 1989) running on a Linux computer. Software was developed using the C programming language. The resulting program is called r.noise and will become part of a future release of GRASS. Invoking the r.noise program with the '-help' argument reveals the following help information:

Usage:

r..noise [-v] input=residential_map output=name dB=decibel distance=distance power=power

Parameters:

input	Map with integer number of individuals at each location
output	Name of raster map to contain results
dB	Known decibel level
distance	Distance at which the decibel volume is known
power	Decay rate of the sound as a power of distance

The user-provided dB value can be a raw decibel level, an A-weighted value reflecting human perception of single events, peak sound level, or Sound Exposure Level (for sound over time), or day-night average sound levels, or onset adjusted noise, depending on the particular needs of the analysis. Options are not provided within the program to adjust dB levels based on the needs addressed by these different measures.

Consider the output image in Figure 3-4. The requested power of decay was 1.0 with a given probability of decay of 10% at a distance of 10 km. The input map represented a single individual on a single location. Complaint within the innermost contour will be 100%, with contours at 80%, 60%, and 40% in the image.

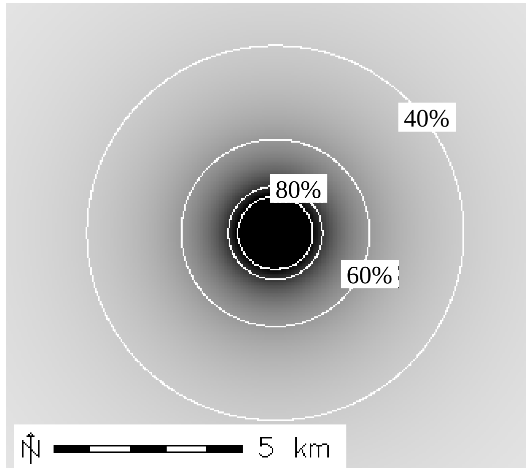

Figure 3-4. Sample decay of probability of complaint.

Appendix 4: Legislation and Policy Guidance for ACUB program

US CODE > TITLE 10 > Subtitle A > PART IV > CHAPTER 159 > § 2684a

Agreements to limit encroachments and other constraints on military training, testing, and operations

Release date: 2004-03-18

(a) Agreements Authorized — The Secretary of Defense or the Secretary of a military department may enter into an agreement with an eligible entity described in subsection (b) to address the use or development of real property in the vicinity of a military installation for purposes of—

(1) limiting any development or use of the property that would be incompatible with the mission of the installation; or
(2) preserving habitat on the property in a manner that—

  (A) is compatible with environmental requirements; and
  (B) may eliminate or relieve current or anticipated environmental restrictions that would or might otherwise restrict, impede, or otherwise interfere, whether directly or indirectly, with current or anticipated military training, testing, or operations on the installation.

(b) Eligible Entities — An agreement under this section may be entered into with any of the following:

(1) A State or political subdivision of a State.
(2) A private entity that has as its stated principal organizational purpose or goal the conservation, restoration, or preservation of land and natural resources, or a similar purpose or goal, as determined by the Secretary concerned.

(c) Inapplicability of Certain Contract Requirements — Chapter 63 of title 31 shall not apply to any agreement entered into under this section.

(d) Acquisition and Acceptance of Property and Interests —

(1) An agreement with an eligible entity under this section may provide for—

(A) the acquisition by the entity of all right, title, and interest in and to any real property, or any lesser interest in the property, as may be appropriate for purposes of this section; and

(B) the sharing by the United States and the entity of the acquisition costs.

(2) Property or interests may not be acquired pursuant to the agreement unless the owner of the property or interests consents to the acquisition.

(3) The agreement shall require the entity to transfer to the United States, upon the request of the Secretary concerned, all or a portion of the property or interest acquired under the agreement or a lesser interest therein. The Secretary shall limit such transfer request to the minimum property or interests necessary to ensure that the property concerned is developed and used in a manner appropriate for purposes of this section.

(4) The Secretary concerned may accept on behalf of the United States any property or interest to be transferred to the United States under the agreement.

(5) For purposes of the acceptance of property or interests under the agreement, the Secretary concerned may accept an appraisal or title documents prepared or adopted by a non-Federal entity as satisfying the applicable requirements of section 301 of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (42 U.S.C. 4651) or section 3111 of title 40, if the Secretary concerned finds that the appraisal or title documents substantially comply with the requirements.

(e) Acquisition of Water Rights — The authority of the Secretary concerned to enter into an agreement under this section for the acquisition of real property (or an interest therein) includes the authority to support the purchase of water rights from any available source when necessary to support or protect the mission of a military installation.

(f) Additional Terms and Conditions — The Secretary concerned may require such additional terms and conditions in an agreement under this section as the Secretary considers appropriate to protect the interests of the United States.

(g) Funding —

(1) Except as provided in paragraph (2), funds authorized to be appropriated for operation and maintenance of the Army, Navy, Marine Corps, Air Force, or Defense-wide activities may be used to enter into agreements under this section.

(2) In the case of a military installation operated primarily with funds authorized to be appropriated for research, development, test, and evaluation, funds authorized to be appropriated for the Army, Navy, Marine Corps, Air Force, or Defense-wide activities for research, development, test, and evaluation may be used to enter into agreements under this section with respect to the installation.

(h) Definitions — In this section:

(1) The term "Secretary concerned" means the Secretary of Defense or the Secretary of a military department.

(2) The term "State" includes the District of Columbia, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Marianas, and the territories and possessions of the United States.

For an example of a typical conservation easement, click here for the PDF document: Conservation easement agreement

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14. ABSTRACT

This project used geographic information system (GIS) map layers in an analysis of historic land use and growth in the region. These GIS layers were then used again as input to the LEAM Land Use Change model to project urban growth around Fort Knox into the future. Historical land use maps, current and future highway system plans, and municipal zoning information all contributed to forecasting residential and commercial development.

The historic trend has been a growth rate of roughly 2% per decade in the region surrounding Fort Knox. In 1972, the percent of urban development here was 1.37%. That figure grew to 6.54% in 2001 and will continue to rise as more and more of the area becomes attractive to people to build there. The prospect for the future, however, is that civilian encroachment around Fort Knox will only continue.

Model simulations indicate that the areas south and west of Fort Knox are those at the greatest risk for urban encroachment, although there is substantial urban sprawl emanating from Louisville to the north. One way to limit future urban encroachment would be to use those areas identified in the Southeastern Ecological Framework Study as a starting point in investigating potential opportunities for conservation agreements between Fort Knox and surrounding land holders. A scenario using the Framework was modeled for this project.

15. SUBJECT TERMS
encroachment, landscape planning, military training, urbanization, Fort Knox, KY

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